AN ABSTRACT OF THE THESIS OF

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Title: Establishment Tolerance of Six Native Sagebrush Steppe Species to *Imazapic* (PLATEAU®) Herbicide: Implications for Restoration and Recovery.

Abstract approved:

Dr. David A. Pyke   Dr. Patricia S. Muir

Scientists and land managers realize that integrated weed management (IWM) strategies are needed to attain successful and lasting improvements of weed infested landscapes. At this time no broadly reliable and environmentally safe IWM strategy has been developed to control exotic annual grasses that dominate many ecosystems of the northern Great Basin. This study determined the efficacy of several nascent control strategies at a site near Mountain Home, ID, USA with particular emphasis on the tolerance of native species to chemical control techniques applied before their emergence. In autumn 2002, prescribed burning and a single preemergent application of imazapic (PLATEAU®) herbicide were used separately and combined to control medusahead wildrye (*Taeniatherum caput-medusae* (L.) Nevski) and cheatgrass (*Bromus tectorum* L.). Seeds of six native perennial species, selected for their range of life histories and ability to provide effective competition, were planted as monocultures two-weeks after fire and herbicide applications. A monthly census determined native seedling emergence and survival from late winter through autumn 2003. In addition, end-of-season population size and reproduction were determined for both exotic annual grasses in each treatment. We hypothesized that application of imazapic would reduce

and delay emergence, cause earlier mortality rates, and lower overall persistence of seeded natives because of adverse impacts to early seedling development throughout the growing season. Burning and imazapic applications combined would amplify these effects with reduced plant residue cover and increased surface evaporation. Prescribed treatments reduced densities of mature exotic annual grasses by 31.1% for burning alone, 79.1% for imazapic alone, and 92.1% for areas with burning and imazapic combined when compared to untreated controls. Few seedlings of globemallow (*Sphaeralcea grossulariifolia* (Hook & Arn.) Rydb.) emerged from any treatment due to extreme dormancy and/or poor site adaptation. Significant responses of the five remaining native species fell into three general patterns associated with three functional/structural plant groups. Deeper-rooted perennials, big squirreltail (*Elymus multisetus* M.E. Jones) and Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth), showed positive responses to imazapic applications. For *E. multisetus*, more seedlings emerged in areas treated with imazapic alone than in any other treatment ($P<0.01$). Rather than impacts from imazapic application, *E. multisetus* seedlings emerged earlier in unburned versus burned areas ($P<0.01$) likely due to greater moisture retention and moderated temperature extremes from the presence of surface litter. For native dicots, Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle and Young) and western yarrow (*Achillea millefolium* L. var. *occidentalis* DC.), overall emergence was reduced by an average of 20% in burned relative to unburned plots likely because of variable surface temperatures, frost heaving of the upper soil profile, and more rapid evaporation of available moisture early in the growing season. Emergence was 3.2 and 2.2 times sooner for *A. tridentata* ($P=0.02$) and *A. millefolium*

(P=0.02) on unburned relative to burned treatments for reasons similar to those of deeper-rooted perennials. *A. millefolium* seedlings experienced particularly slow emergence in plots burned and treated with imazapic. Prescribed burn plots had seedlings emerge 2.1 times (P=0.04) sooner than burning with imazapic. This implies that imazapic, as well as burning, may be slowing seedling development of this species. Burned plots also exhibited seedling mortality in nine-tenths the time than unburned plots for *A. tridentata* and *A. millefolium* (P=0.03 and P=0.05). The shallow-rooted perennial, Sandberg bluegrass (*Poa secunda* J. Presl.), was the only seeded species to carry on a population into the fall of 2003. Untreated controls had 3.3 times more plants per m^2 than plots applied with imazapic alone (P=0.03) implying a degree of imazapic intolerance for this species. Although this research indicates that some native arid species are tolerant to imazapic, experiments should continue to incorporate fall preemergent applications of this herbicide to improve our understanding of native species responses and foster the development of an effective IWM strategy for arid rangelands of the Great Basin.

Establishment Tolerance of Six Native Sagebrush Steppe Species to *Imazapic* (PLATEAU®) Herbicide: Implications for Restoration and Recovery.

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Steven Bekedam, Author

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INTRODUCTION

Cheatgrass (*Bromus tectorum* L.) and other exotic annual grasses now dominate large expanses of northern Great Basin sagebrush steppe ecosystems of the western U.S. These annuals have been prominent in the Great Basin for over 75 years and fairly recent estimates put cheatgrass infestations over 80 million acres on public lands alone (Pellant and Hall 1994). Characteristics that allow these exotic grasses to dominate include, but are not restricted to, a winter annual C_3 life form, high water and nutrient use efficiencies, minimal seedling establishment requirements, broad phenotypic plasticity, early and rapid root and shoot growth that preempt available resources to surrounding native plants, high reproductive capacity with prolific seed production, and high grazing tolerance (Hulbert 1955; Harris and Wilson 1970; Melgoza et al. 1990; Reichenberger and Pyke 1990; Young 1991; Monsen 1994; Tausch et al. 1994; Vallentine and Stevens 1994). These characteristics allow for high seedling recruitment regardless of the type and intensity of ecosystem disturbance. Progressive dominance by exotic annual grasses leads to the loss or reduction of native species unable to compete essentially lowering the biotic integrity of invaded areas.

Weed management tactics have been implemented to significantly reduce exotic annual populations and their seed sources so systematic restoration of native rangeland plants may take place. Tactics tested include mowing, proper grazing regimes, prescribed fire, mechanical tillage, herbicides, biological control, and soil nutrient manipulation. Unfortunately, many of these tactics have proven ineffective because of the broad phenological plasticity exhibited by exotic annual grasses. Not to mention, those tactics that are locally successful are often not entirely cost effective or simple to execute on larger expanses of impaired rangelands.

Research scientists and land managers realize that none of these tactics can solely control exotic annual grasses in this region and that proper restoration of these areas may require more active approaches. Employing several control techniques in planned sequence, forming in part an integrated weed management (IWM) strategy, is necessary for successful and lasting improvements of degraded landscapes (Sheley et al. 1996; DiTomaso 2000; Masters and Sheley 2001). These strategies are successful because they impart three fundamental characteristics of proper rangeland restoration: weed control, seedbed preparation, and revegetation (Masters and Sheley 2001). IWM strategies ultimately have higher potential to reduce dominance of weedy species, increase native species diversity, improve forage production, raise the potential for wildlife and recreational use, and thereby reverse resource degradation of treated areas.

Forming an appropriate weed management strategy for rangelands requires the evaluation of all tactics available, keeping in mind their degree of weed control, cost, suitability, and level of impact to native species and the surrounding environment (Sheley et al. 1999). Proper IWM strategies for entire regions overrun by exotic species must ultimately have broad, cost effective, multiple scale managerial applications. At this time no broadly reliable and environmentally safe IWM strategy has ever been developed to control annual invasive grasses on Great Basin rangelands. Eckert and Evans (1967), Evans et al. (1967), and Young et al. (1969) all combined mechanical tillage and herbicides for effective weed control, but this strategy is not viable in areas with changing topography. Whitson and Koch (1998) were successful using herbicides without mechanical tactics for weed control followed by intense grazing and seeding of native perennial grasses directly into residual weed stands. Unfortunately, environmental concerns, cost, and lack of herbicide selectivity have land managers hesitating to use most chemical herbicides.

Improvements in herbicide chemistry, cost, and application techniques in the last decade have moved this tactic to the forefront for weed control and integrated management associated with aridland restoration. Many new herbicides have lower dosage requirements, reduced animal toxicity, greater flexibility of application times and techniques, and breakdown into the surrounding environment faster than their predecessors. Improvements have been particularly remarkable for herbicides within the imidazolinone family, long favored for their lower dosages and broad application potential. Imidazolinone herbicides, first discovered in the mid 1970's, inhibit amino acid synthesis in plant cells through the inactivation of the plant enzyme acetohydroxyacid synthase (AHAS). AHAS catalyzes the production of leucine, isoleucine, and valine, amino acids required for proper plant function and growth (Moberg and Cross 1990; Stidham 1991). Primary uptake of imidazolinones is by absorption through leaves or roots. Herbicides are translocated into plant meristems ending active plant cellular division and growth, but more importantly, disrupting photosynthate translocation and hormonal balance for the entire plant (Shaner 1991). Physical injury from herbicide contact is slow to develop, averaging about 1 to 2 weeks, and is typically exhibited by reduced root growth of susceptible plants. Any selectivity within this herbicide family is based on a target plant's ability to break down the herbicide before it reaches toxic proportions (Colquhoun 2001). This ability is dictated by differences in plant absorption, translocation, rate of metabolism, and sensitivity of the site of action to the herbicide (Shaner and Mallipudi 1991). Plant response also depends on which imidazolinone herbicide is applied, since all vary considerably, particularly in site of action sensitivity. Herbicides first produced in the imidazolinone family include imazapyr, imazethapyr, and imazaquin. Imazapic, an imidazolinone produced by BASF with the trade name PLATEAU® beginning in the mid-1990's, is now being advocated as the most likely candidate for exotic annual grass control in the Great Basin (Mike Pellant, BLM, personal communication).

Imazapic activity, like all other herbicides, is based on its soil mobility, soil adsorption, and other residual effects that vary due to site-specific environmental conditions including plant available soil moisture, soil pH, soil temperature, microbial activity, soil texture, soil organic matter, and plant community structure (Shaner and Mallipudi 1991; Malefyt and Quakenbush 1991). As a result, the average half-life of imazapic after application is broad, ranging from about 7 to 150 days (BASF unpublished data). This range of persistence has important temporal significance for the development of an integrated weed management strategy for rangelands dominated by exotic annual grasses. Imazapic, like its predecessors, can be applied as a preemergent (or soil-applied) product. If applied to field soil in autumn, it can provide residual exotic annual grass control by killing any fall seedlings that germinate while the herbicide remains active in the soil water solution (Colquhoun 2001). This may allow spring-germinating natives to establish during receding herbicidal activity and absence of competition for soil moisture from exotic annual grass seedlings.

Several recent studies have evaluated effects of imazapic and other imidazolinones on rangeland exotic species and natives with restorative potential. Masters et al. (1996) discovered site-specific improvement of native perennial grass establishment as a result of spring preemergent imazapic and imazethapyr applications in eastern Nebraska. In an expanded follow up study, Masters et al. (1998) found that imazapic applied in autumn at a fraction of other appropriate herbicide doses gave a greater degree of control for leafy spurge (*Euphorbia esula* L.), leaving native mature forbs and cool and warm season grasses unaffected. Fry et al. (1997) detected more variable results when looking at weed control efficacy and biomass of seeded buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) as a function of preemergent herbicide type. While imazethapyr was generally successful across all Kansas and Nebraska sites, imazapic efficacy was more site and weed specific. Beran et al. (1999a, 1999b, and 2000) documented higher establishment rates of seeded prairie grasses and forbs in imazapic and imazethapyr plots compared to controls when seeds were planted both in monoculture and in mixture. Washburn and Barnes (2000) compared pre and post emergent imazapic and imazapic plus 2,4-D applications in Kentucky. Forb seedling emergence was limited with preemergent application of both treatments but most native forbs and grasses did persist eleven months after treatment application. Finally, Shinn and Thill (2002) conducted trials in northwest Idaho, finding that postemergent applications of imazapic controlled downy brome (*B. tectorum*) and other annual grasses. Mature plants of desirable smooth brome (*Bromus inermis* Leyss.) were injured by applications as low as 70 and 140 g/ha but sufficiently recovered one year after treatment.

Although this literature provides a foundation on which to incorporate imazapic into an appropriate integrated management approach, most trials have involved weeds and native grasses and forbs of Great Plains states. Little documented information exists of imazapic efficacy on western weeds and tolerance by arid to semiarid vegetation (PLATEAU® label. 2002. BASF Corporation, Research Triangle Park, NC, USA). As a result, many federal agencies and universities in the western U.S. are currently determining imazapic tolerance levels of local weeds and native species. Initial studies of imazapic control of exotic annual grasses in the Great Basin have been positive (Vollmer and Vollmer 2001; Ransom et al. 2001; Shinn and Thill 2004; and several Idaho/Oregon Bureau of Land Management Field Offices, personal communication) and have resulted in some standard application suggestions. More research is necessary, however, that continues to determine imazapic efficacy and more importantly, its potential impact on nontarget natives as we further develop integrated strategies for proper weed control and native revegetation.

In this study, we used preliminary imazapic research to fix application rates and times for exotic annual grass control and tested end-of-season density and reproduction of these annual grasses and tested herbicide tolerance of native seedlings at a site north of Mountain Home, ID. Imazapic trials indicate that application rates will vary depending on the dominant target species and the condition of the soil surface where these target plants most commonly occur. A bare soil surface, i.e. free from plant residues, would require a lower application rate to successfully reduce target species. In locations where plant residues are much thicker, a higher application rate is needed to allow the herbicide to effectively penetrate the residue and come in contact with the soil surface. This study used these two standard application conditions (bare soil and surface litter) to evaluate native plant establishment and survival. The bare soil surface was created using fire to remove standing vegetation and residues similar to conditions found after a typical late summer-early fall wildfire.

Restoration of a functional sagebrush steppe community is characterized in part by the re-establishment of various plant functional groups needed to stimulate autogenic repair processes (Whisenant 1999). Multiple growth forms and life history strategies are often needed to allow these repairs to take place. Once diverse plant communities are intact, they may even have the potential to confer weed resistance by effectively obtaining available resources during the same time and in the same space as exotic annual plants (Sheley et al. 1996). For this study, native species were selected that exhibited a range of growth forms and life histories and were suspected, once established, to provide effective competition against recurring exotic annual grasses (Table 1).

Study Purpose and Hypotheses

The purpose of this study was to investigate the emergence and establishment of six native plants sown from seed after fire and imazapic herbicide applications, used separately and in combination, to control two exotic annual grasses, cheatgrass (*B. tectorum*) and medusahead wildrye (*Taeniatherum caput-medusae* (L.) Nevski). An additional treatment, manual exotic annual grass removal, was implemented to serve as a check for native plant establishment in the sole reduction of competition from the two exotic grasses. We hypothesized that all treatment combinations involving herbicide would not only reduce emergence and first-year fall survival of native seedlings

Table 1. Six native sagebrush steppe species selected for the imazapic seeding trial as determined by site potential, seed availability, prior seeding success, overall competitive ability, mature growth form, and life strategy (most seed sources unknown). Nomenclature from the USDA PLANTS Database (2004).

Species	Common name	Cultivar / Collection	Basic growth form & strategy
Shrubs			
Artemisia tridentata Nutt. ssp. *wyomingensis* (Beetle and Young)	Wyoming big sagebrush	-----	late seral, keystone shrub species for sagebrush steppe; large quantity, wind dispersed seed; shallow seed depth; deep taproot
Grasses			
Elymus multisetus M.E. Jones	big squirreltail	Sand Hollow / Emmett, ID	early to midseral, cool season perennial bunchgrass; early phenology; large seed
Poa secunda J. Presl	Sandberg bluegrass	High Plains / Campbell, Natrona, and Uinta Co.'s of Wyoming.	short, cool season, perennial bunchgrass with shallow roots and early phenology; medium sized seed
Elymus wawawaiensis J. Carlson & Barkworth	Snake River wheatgrass	Secar / Lewiston, ID	tall, cool season perennial bunchgrass with deep roots and late phenology; large seed
Forbs			
Achillea millefolium L. var. *occidentalis* DC.	western yarrow	Great Northern / Flathead County, Montana	tall, rhizomatous, herbaceous perennial forb; small seed
Sphaeralcea grossulariifolia (Hook & Arn.) Rydb.	gooseberryleaf globemallow	-----	medium height, taprooted, herbaceous perennial forb; small to medium sized seed

compared to both weeded and nonweeded controls, but also affect the timing at which these events occur. Residual imazapic activity would likely delay emergence due to adverse impacts to early seedling development and growth. Herbicide plots would then be expected to show earlier mortality of these later-emerging seedlings. Because lower imazapic rates were applied to burned plots, we expected herbicidal effects on these plots to be similar to those left unburned and treated with higher rates. However, we predicted later and more reduced seedling establishment in burn and herbicide combinations due to increased temperature extremes and surface evaporation from burned plots. Herbicide intolerance by native species, then, is defined in this study as any instance where herbicide treatments under perform weeded or unweeded controls, giving reduced proportional emergence, lower overall fall densities, slower seedling emergence, and/or faster seedling mortality.

Based on these hypotheses, four primary questions of interest were generated to understand weed reduction and subsequent native seedling tolerance to imposed treatments: 1) How effectively were exotic annual weeds controlled in each treatment as measured by remaining weed densities and seeds per plant?, 2) Did herbicide rates on both unburned and burned surfaces achieve the same degree of weed reduction for both *B. tectorum* and *T. caput-medusae*?, 3) Do differences in total proportional emergence and overall seedling survival exist when comparing untreated controls, manual weed removal, or other means of controlling competition, i.e. herbicide, burning, or both?, and 4) Do burn or herbicide combinations affect the rate at which seeded species emerge and survive relative to weeded and untreated controls? Answers to these questions should provide insights into the development of a feasible weed management strategy that will sufficiently control exotic annuals and improve native establishment on similar range sites using these six species.

MATERIALS AND METHODS

Study Site

A study site was selected that: 1) received between 250 and 350 mm (~10-14 inches) of mean annual precipitation; 2) had > 75% of the total plant cover as exotic annual grasses; 3) had < 10% of the total cover as native perennial grasses and shrubs; 4) were suitable for fire and herbicide applications (involving site size, slope, etc.); and 5) had a buffer of at least 100 m from any surrounding nontarget areas.

We located a 35 ha Snake River Plains fan terrace with 0-12% slopes fitting such site criteria in Elmore County, Idaho, USA (43°17'20"N, 115°44'55"W) (Figure 1). This Bureau of Land Management parcel has an elevation range of 1060 to 1100 meters (3475 to 3610 ft) and receives approximately 270 mm of mean annual precipitation according to the nearest weather station 25 km to the southwest (Mountain Home, ID). Precipitation is dominated by cool, wet winter storms traveling predominantly southeast from the Pacific Ocean. Situated at a slightly higher elevation about 2 km from the base of the Danskin Mountains, the parcel likely receives slightly more annual precipitation and snowfall than documented at the nearby station. The PRISM Data Explorer (http://www.ocs.orst.edu /prism/index.html 5 February 2004) based on the PRISM model (Daly et al. 1997) estimates that the site receives about 307 mm (12.1 inches) of mean annual precipitation.

According to the Elmore County soil survey (USDA-SCS, 1991) and field soil texture determinations, the entire 35 ha site is within the loamy 250-305 mm (10-12")

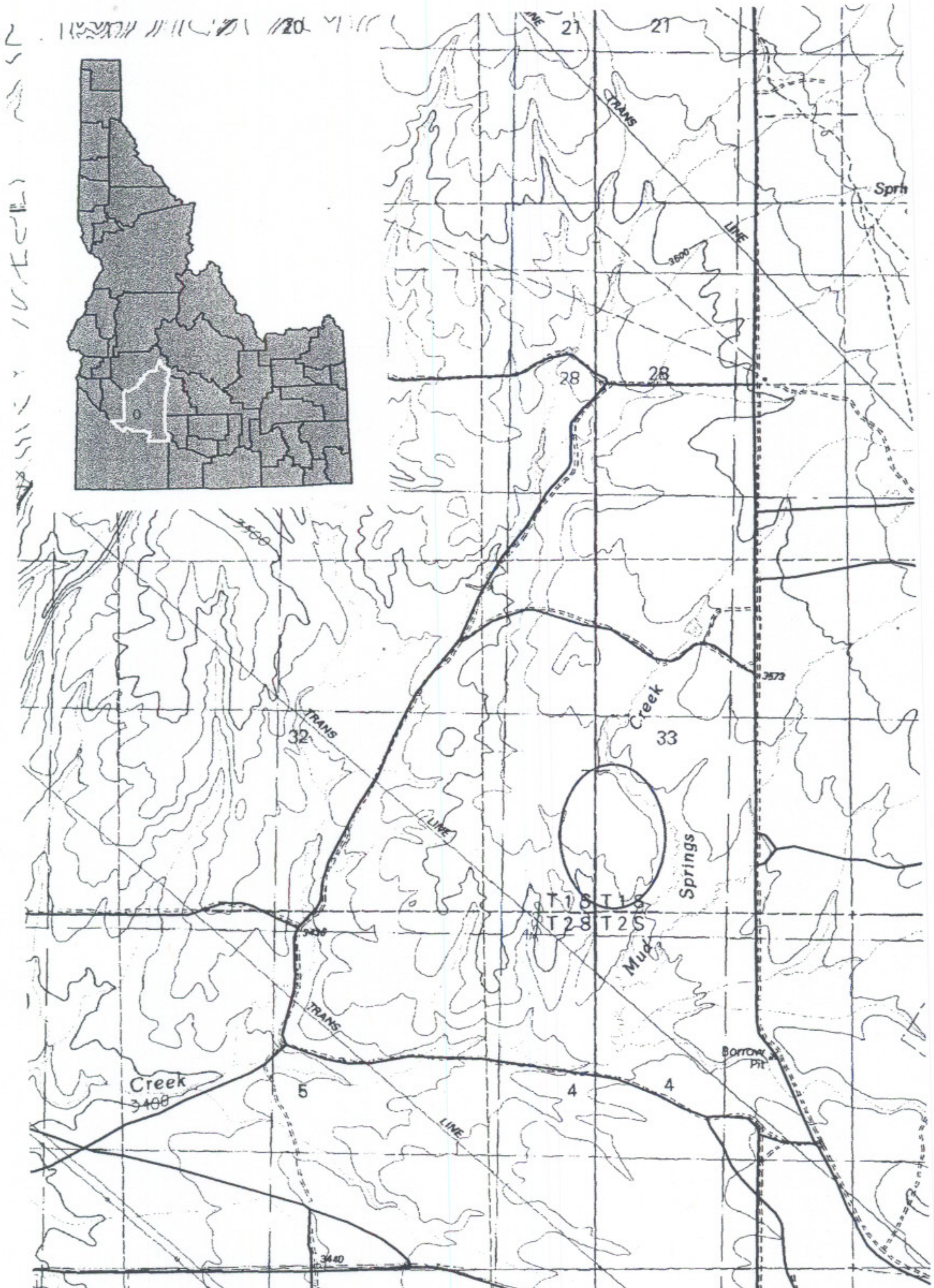

Figure 1. Canyon Creek study site location in Elmore Co., ID, USA (Mayfield SE 7.5 minute USGS quadrangle – T1S, R5E, S33).

ecological site description. The soil is classified as a Lanktree Chilcott loam association with fine, montmorillonitic, mesic Xerollic Haplargid and Abruptic Xerollic Durargid soils. The primary difference between these two soil components is a duripan layer between 51 cm and 102 cm for the Chilcott soil (30% of the area), which could potentially impede roots of mature plants but should not affect seedling establishment. The potential natural community for this ecological site is Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve ssp. *spicata*), with approximately 70% grass, 5% forb, and 25% shrub composition by weight (USDA-SCS 1991). The existing plant community is dominated by *T. caput-medusae* with smaller areas of *B. tectorum* that collectively make up approximately 75-85% of the total plant cover. One to ten percent of the remaining vegetation cover is comprised of several native perennial grasses dispersed across the landscape including *Poa secunda* J. Presl, *Elymus multisetus* M.E. Jones, *Achnatherum thurberianum* (Piper) Barkworth, *Leymus cinereus* (Scribn. & Merr.) A. Löve, and *P. spicata*. This site was grazed eight months of the year (October to May) as part of a large grazing allotment that uses both private and public lands surrounding the desired study site. A small grass wildfire (<200 ha) burned the entire study area in late summer of 2001, one year before site selection; previous fire history is unknown. Preliminary site surveys in August 2002 for specific block / plot locations included determination of general soil characteristics, verification of soil mapping units, and measurement of vegetation composition (Table 2). Data on cover of *B. tectorum*, *T. caput- medusae*, and mature native perennial grasses were collected using the line-point intercept technique on four randomly located 30-m transect lines, with points read every

Table 2. Block parameters measured August 2002 prior to weed control treatments and soil parameters measured at peak growing season (April 2003) at the Canyon Creek study site near Mountain Home, ID, USA. Sample standard errors (± 1 SE) presented in parentheses where applicable.

	Block 1	Block 2	Block 3	Block 4	Block 5
Aspect:	E	N to NE	N	E	W
Slope:	4 – 6 %	13 – 15 %	0 – 1 %	5 – 7 %	10 – 12 %
Associated Macroplots:	1, 2	3, 4	5, 6	7, 8	9, 10
Predominant Soil Texture (n=4) **(@ 10 cm):**	clay	silty clay	silty clay	clay	silty clay
Soil Analyses (0-10 cm) (n=5):					
pH:	6.90 (0.04)	6.88 (0.05)	6.93 (0.03)	6.98 (0.05)	6.85 (0.03)
% OM (Loss on Ignition technique):	3.98 (0.22)	4.02 (0.08)	4.79 (0.31)	4.47 (0.40)	4.15 (0.08)
% CEC (meq/100g):	15.98 (0.87)	14.83 (0.81)	18.90 (0.99)	19.50 (1.14)	17.75 (0.69)
Existing Vegetation (% Cover):					
T. caput-medusae:	74.0 %	72.6 %	57.4 %	79.9 %	68.3 %
B. tectorum:	4.5 %	6.3 %	18.5 %	9.2 %	12.0 %
total exotic annual:	78.5 %	79.9 %	75.9 %	89.1 %	80.3 %
P. secunda:	9.9 %	1.6 %	0.80 %	0.0 %	4.50 %
E. elymoides:	0.0 %	0.0 %	0.0 %	0.80 %	0.40 %
total native perennial:	9.9 %	1.6 %	0.80 %	0.80 %	4.90 %
Initial Weed Density (n=4) **(plants / 0.25m^2):**					
T. caput-medusae:	80.0 (17.04)	90.75 (16.87)	67.25 (8.22)	69 (14.28)	54.25 (16.09)
B. tectorum:	9.75 (7.25)	10.0 (3.58)	15.0 (6.72)	16.0 (7.61)	17.0 (4.67)
Average Litter Depth (cm) (n=16):	0.80 (0.18)	0.60 (0.11)	0.44 (0.10)	0.40 (0.08)	0.60 (0.14)

30 cm, in each future block. Weed densities were also determined at four random 0.25-m^2 locations per proposed block to verify similar weed coverage across the entire study site.

Litter depth to the nearest centimeter was measured from sixteen random locations in each block area to help determine herbicide application rates. To determine field season precipitation, two rain gauges were installed within 100 m of the site using 15 cm (6") diameter PVC tubes containing 1.0 liter of antifreeze and 0.5 liters of oil covered with wire screen. Gauge contents were measured during each site visit (Appendix A). One air and one soil temperature probe was installed approximately 200 m from the center of the study area. The air probe took readings 100 cm aboveground and the soil probe took measurements 10 cm belowground. These probes recorded temperature every 30 minutes during the entire experiment and monthly averages are summarized in Appendix A.

Experimental Treatments

We used a split block completely randomized design to answer the four questions of interest concerning weed control and native seedling establishment. Blocks were established to account for slope and aspect changes across the site and these formed replicates of all treatment combinations (n=5). Each replicate block (approximately 1 ha) was positioned perpendicular to prevailing winds and consisted of two macroplots, each randomly assigned a burning treatment (burned vs. unburned) (Figure 2). Burned macroplots were buffered by a minimum of 30 m from those remaining unburned. Each macroplot was divided into two 25- X 25-m split plots that were randomly assigned an herbicide or no herbicide treatment. Herbicide plots were

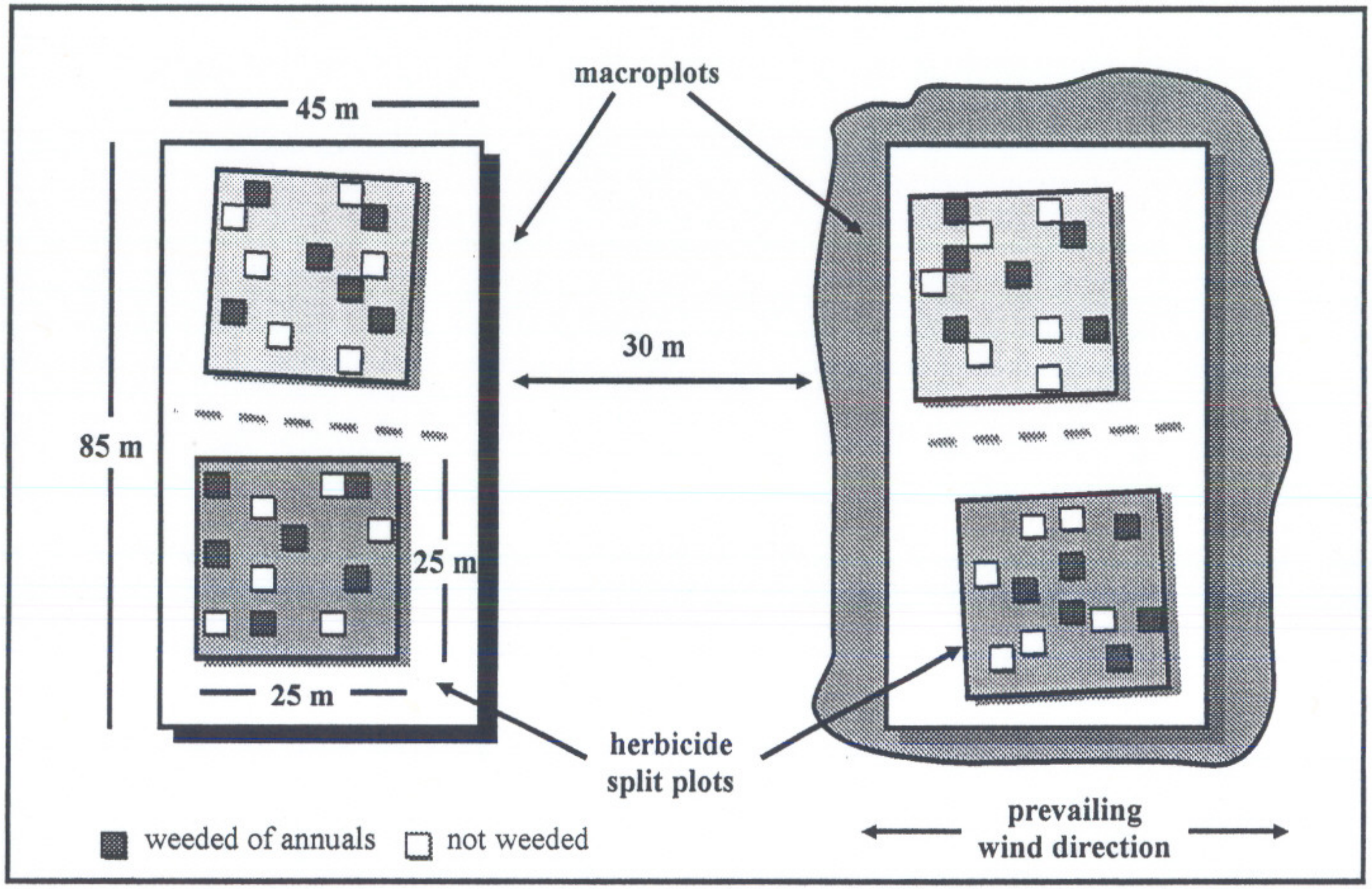

Figure 2. Block structure for the Canyon Creek study site (one of five total blocks) (n=5). Macroplots and split plots were randomly assigned a burn and herbicide treatment and positioned perpendicular to prevailing wind direction and upslope position. One meter subplots were randomly assigned a seeded native species and a weeding treatment. Dashed lines indicate drift fencing and shaded polygon indicates extent of burn prescription.

installed a minimum of 15 m from no herbicide plots. Drift fences were erected between split plots to avoid herbicide drift during application and the movement of herbicide-bound soil particles from affecting nearby plots. A three-strand wire fence was also constructed to protect the entire site from livestock.

Timing of treatments is critical to the control of exotic annual grasses and an effective weed management strategy. Prescribed burning occurred on 29 October 2002 (Table 3). Two burn macroplots were close in proximity and were burned as one large burn (burn #2). Each burn area was enclosed by retardant foam and lit as a strip-head fire typical of many fall wildfires. Aboveground preburn and postburn fire fuels were collected from five randomly located 0.25-m^2 quadrats in each burn area. Fuel samples were later dried at 60°C for 48 hours and weighed to determine total fuel consumption (Appendix B). On the day of the burn, two samples of aboveground fuel were also collected randomly within each burn area for fuel moisture measurements. Fire flame estimates were difficult to obtain due to the degree of hazard, topography, and skill of the observer. During each fire, flame height, depth, angle, and length were estimated for several flame runs to obtain general descriptive parameters of each burn (Table 3). Rate of spread, the time fire takes to move a specified distance, was estimated using three 1.5 m stakes placed one meter apart in the direction of the wind and likely path of a run of flames for each burn. Fireline intensity and heat per unit area for each burn were calculated using these parameters and methods described in Rothermel & Deeming (1980).

Table 3. Prescribed burn parameters, average burn observations (n = 3), and average fire fuel data (n = 5) for all four burns measured on 29 October 2002 at the Canyon Creek study site near Mountain Home, ID, USA. Parentheses denote sample standard errors (± 1 SE).

	Burn #1	Burn #2	Burn #3	Burn #4
Local Weather:				
Conditions:	overcast	overcast; light rain	very light rain	very light rain
Air Temp:	47°C	45°C	45°C	47°C
Relative Humidity:	67%	72%	72%	71%
Wind Speed:	6.7 km/h	8.3 km/h	8.3 km/h	8.3 km/h
Wind Direction:	SW to NE	NW to SE	NW	NW
Burn Parameters:				
Burn Size:	0.40 ha	1.10 ha	0.40 ha	0.40 ha
Burn Treatment:	strip-head	strip-head	strip-head	strip-head
Burn Observations:				
Average Rate of Spread:	0.66 m / sec (0.17)	0.63 m / sec (0.19)	0.29 m / sec (0.11)	0.44 m / sec (0.06)
Average Residence Time:	5.2 sec (0.60)	6.2 sec (0.44)	5.0 sec (0.50)	3.7 sec (0.17)
Fireline Intensity (kW/m):	63.02 (30.8)	42.47 (14.9)	17.31 (4.6)	35.79 (5.5)
Heat per Unit Area (Btu/m^2):	5729.10	4044.80	3581.40	4880.50
Fire Fuel Data:				
Preburn Fuels (g):	15.55 (3.46)	13.77 (1.09)	16.64 (1.47)	14.91 (2.22)
Postburn Fuels (g):	6.14 (1.00)	7.46 (0.82)	8.22 (1.66)	5.60 (1.26)
Average % Consumption:	60.5 %	45.8 %	50.6 %	62.4 %
% Fuel Moisture:	2.9 % (0.23)	4.0 % (0.11)	3.9 % (0.01)	3.8 % (0.08)

Imazapic was applied five days after prescribed burning on 5 November 2002 using a one person-operated All Terrain Vehicle with a 12 ft (3.66 m) boom sprayer. Standard rates of herbicide application are typically chosen to balance the most effective exotic annual grass control with lowest possible cost, potential risk to existing native species, and overall environmental impact. Based on local imazapic research, the purpose of the study, communication with BASF researchers, and site litter measurements, two rates of herbicide were chosen for this study: one for areas where plant litter had been partially removed by fire (see Table 3 for percent fuel consumption of burned areas) and one for areas where litter remained intact. Herbicide was applied before annual grass emergence as follows: 280 g of active ingredient (ai)/ha (4 oz/acre) for those areas burned and 420 g ai/ha (6 oz/acre) for areas with intact plant litter. Methylated seed oil adjuvant was added at 2.34 l/ha (1 quart/acre) to the application mixture to improve herbicide contact with the soil surface for uptake by target species. The sprayer delivered the mixture at a volume and pressure of 168 l/ha (18 gal/ac) at 242 kPa (35 psi) through seven 11003 AI Flatfan Teejet tipped nozzles. Herbicides were applied under environmental conditions consisting of 8.3 °C (47°F) air temperature, 13.3 °C (56°F) soil temperature at 5 cm deep, winds of 5-6 km/h (3-4 mph), and 20% relative humidity.

Native seeds of all six species were planted from 20 November to 27 November 2002, two weeks after preemergent herbicide application. Native seeds were obtained from four different sources in early fall of 2002. Seeds of *A. tridentata* ssp. *wyomingensis* (Wyoming big sagebrush) and *Sphaeralcea grossulariifolia* (globemallow) were from the Bureau of Land Management Regional Seed Warehouse in Boise, ID. *Elymus wawawaiensis* (Secar Snake River wheatgrass) seed came from the Natural Resource Conservation Service National Plant Materials Center in Pullman, WA. *Elymus multisetus* (Sand Hollow squirreltail) seed was sent from the USDA - Agricultural Research Service Forage and Range Research Laboratory in Logan, UT. Finally, *Achillea millefolium* var. *occidentalis* (Great Northern western yarrow) and *Poa secunda* (High Plains Sandberg bluegrass) seeds came from the Natural Resource Conservation Service National Plant Materials Center in Bridger, MT. Seeds were sent ready for planting with the exception of *A. tridentata*, which was blown with a seed blower for 2 minutes at low speed to remove chaff and inflorescence branches. Seed viability was determined in the lab before planting using the tetrazolium chloride technique (AOSA 2000). Average seed viabilities were as follows: *A. millefolium* (80%), *A. tridentata* (81%), *E. wawawaiensis* (96%), *P. secunda* (84%), *E. multisetus* (89%), and *S. grossulariifolia* (89%).

Just before sowing native seeds, twelve 3-m^2 subplots were randomly located within each herbicide and non-herbicide plot. Steel bars (1 cm X 15 cm) were driven into the corners of each subplot to aid in relocation. A central 1-m^2 area of each subplot was seeded in monoculture with one of the six randomly selected native species. Seeds were systematically hand placed into 324 known locations (an 18 X 18 grid) of each subplot, using a twined seeding grid, giving each seed separation of about 5.6 cm. This seed density was chosen to provide sufficient numbers of seedlings to evaluate emergence and survival. The following seeding depths were used: 1.5-2.0 cm for *E. wawawaiensis* and *E. multisetus*, 1.0-1.5 cm for *P. secunda* and *S. grossulariifolia*, and just under the surface litter and/or soil for *A. millefolium* and *A. tridentata*. Every seed location received at least one live seed. Seeding resulted in two subplots per native species per split plot. A final treatment, manual weed removal, was assigned to one of these subplots per species.

Starting on 8 February 2003 prior to native seedling emergence, exotic annual weeds were manually removed from 1.25-m^2 of one subplot per species per treatment combination, centered on the 1-m^2 seeding grid. Hand-weeding was performed to provide a weed-reduced control for both herbicide application treatments. Exotic annuals were removed with care so that soil disturbance was minimized. Weeding continued every four weeks for a 12 week period ending in late April 2003 when exotic annuals reached seed maturity.

A monthly census of each plot determined native seedling emergence and survival from late winter 2003 through autumn 2003. Mid-census dates were: 5 March, 30 March, 25 April, 5 June, 15 July, and 5 December 2003. In each census period, seedling presence was measured for each seed location. Soil was collected on the last day of each census period to estimate soil moisture in each treatment and to use it as a potential covariate with seedling establishment. One random location per split plot was selected and approximately 100 g of soil was collected from 10 to 15 cm below the soil surface. Gravimetric soil moisture (%) was calculated from pre and post drying of the soil (48 hours at 105°C) (Appendix C). Analyses of soil characteristics were also conducted to help explain seedling responses and factors affecting any remaining herbicide activity. At the end of the 25 April 2003 census period during optimal spring growth, 0 to 10 cm soil cores were collected from 10 random locations per split plot. These samples were loosely sieved, thoroughly mixed, and analyzed by the Central

Analytical Laboratory, Oregon State University in Corvallis, OR for soil pH, organic matter, and cation exchange capacity (Table 2 and Appendix D). During the 5 June 2003 census period, mature *B. tectorum* and *T. caput-medusae* plants were counted in 8 randomly selected 5- X 5-cm squares (2.5% of the total plot area) throughout each species subplot to determine extent of weed control for each burn, herbicide, and hand-weeding treatment. Mature *B. tectorum* and *T. caput-medusae* plants were also systematically removed from each species subplot on census periods 5 June and 15 July respectively (at the end of the growing season for each weed) by randomly placing a 10- X 10-cm PVC frame over the grid until at least 50 plants were removed per weed species. If less than 50 plants were found in a subplot, every available plant was collected. Average number of filled seeds and flowering stems per weed species were obtained from these plants.

STATISTICAL ANALYSES

Weed Reduction

Density and seed set of remaining *T. caput-medusae* and *B. tectorum* plants were analyzed using mixed model analysis of variance techniques (SAS, PROC MIXED; SAS Institute 2003). ANOVAs compared total weed densities and seed set per plant from each treatment for each weed species. Only 8 of 28 treatment comparisons are needed to answer our questions relating to weed reduction. Although only seven degrees of freedom were present to allow these contrasts of interest without an error correction, we are confident in making one additional contrast without applying an error adjustment (M. Huso, Oregon State University statistician, personal opinion). Although not reported, model assumptions, normality, and equal variance were checked before each analysis by examining calculated residuals. Back-transformed statistics are reported when necessary as multiplicative effects of the response. Standard ANOVA tables and desired contrasts of both weed density and seed set for *B. tectorum* and *T. caput-medusae* are presented in appendices E through H.

Seedling Establishment Amounts

Total estimates of seedling establishment were also analyzed using analysis of variance (ANOVA) techniques (SAS, PROC MIXED). Mixed ANOVA models were created for total proportional emergence and total overall density of each native plant species. ANOVAs for total emergence compared the total proportion of plants that had emerged in each treatment by the end of the 2003 growing season. ANOVAs for overall density compared the number of live seedlings found at the end of the 2003 fall growth period in each treatment.

The same 8 of 28 possible treatment comparisons as weed reduction analyses were needed to isolate treatment effects relating to our key questions of interest concerning total seedling emergence and overall density. These eight planned contrasts were again examined without any error adjustment. Model assumptions, normality, and equal variance were checked before each analysis by examining calculated residuals. Back-transformed statistics are again reported when necessary as multiplicative effects of a response. Standard ANOVA tables for seedling emergence and survival and their contrasts are presented in appendices I through J.

Emergence and Survival Rate Analyses

Rates of seedling emergence and mortality were investigated using failure time analyses. Classically, the effect of a treatment on the rate at which an event occurs is quantified by comparing the mean number of events per treatment over a fixed period of time. Failure time analysis is preferred because it allows the researcher to compare group survivorship curves over the entire range of event times and it accounts for censored observations, individuals that are not followed to an event by study completion and/or are lost from the experiment (Fox 2001). First derived for observational studies in the health sciences, both parametric and nonparametric failure time analyses have been expanded to explain several ecological phenomenon (Muenchow 1986, Pyke and Thompson 1986, Fox 1990, and Hutchings et al. 1991).

For emergence times, similar to an example in Fox (2001), although seeds were planted into experimental units (species subplots) in autumn 2003, only after proper spring temperature and moisture does measurement begin of emerging individuals. The first census (5 March 2003) represented the number of emerged individuals any time prior to that census date. The measurement endpoint was fixed as 5 June 2003, the last census in which newly emerged individuals were observed. All seed locations not resulting in an emerged individual were considered censored because the fate of seeds in these locations is not known. For seedling mortality, the first survival census was 25 March 03 and ended on 5 December 2003, the last possible census in which a mortality event could be observed. Censored individuals were simply those that remained alive at the end of the experiment because the complete lifespan of these individuals is unknown.

Initially, event time data were explored using PROC LIFETEST (SAS Institute 2003) which yielded life table estimates of both survival and underlying hazard for each time period for each experimental unit. Here survival represents the proportion of individuals that have not yet experienced an event (emergence or mortality) by each census period and hazard is the collective probability of individual events in each interval given that the events for these individuals have not occurred by the beginning of that interval (Fox 2001). PROC LIFETEST estimates can be used to test event rate hypotheses, but these tests do not allow more complex study design elements, i.e. blocking, to account for additional variation. An alternative analysis was to use PROC LIFEREG (SAS Institute 2003), a parametric model building procedure that requires additional assumptions for both survival and hazard distributions over time. Data effectively described by these models, called accelerated failure time models, are defined as having periods of high hazard which are shifted according to each covariate level (Fox 2001). These models require reference probability distributions to be chosen that represent both survival and hazard of accelerated failure time data (see Pyke and Thompson 1986 and Fox 2001 for detailed descriptions of model distributions). For both our seedling emergence and mortality results, a log logistic distribution was chosen to estimate survival and underlying hazard. This distribution was chosen for rates of emergence because we expect rapid increases in emergence as optimum temperatures and moisture become available, reach a maximum, and then decline. Similarly for mortality rates, risk of death would rapidly increase as soil moisture declines and temperatures increase, but this risk would then become reduced with fewer, more drought-resistant plants.

PROC LIFEREG was run using these distribution assumptions to acquire one regression coefficient of average log event time for each experimental unit (subplot) for both emergence and mortality events. These response curve estimates were then placed into a standard mixed model analysis of variance, a technique similar to Meredith and Stehman (1991), which allows for the random effects of the study's experimental design. Model assumptions were examined using calculated residuals, the same 8 of 28 pre-planned contrasts as other analyses were conducted without adjustment, and back-transformed statistics are reported. Results are reported as multiplicative changes in average event times. ANOVA tables and contrasts for each emergence and mortality analysis by species are presented in appendices K through L.

RESULTS

The 2003 growing season was warmer and often drier relative to long-term averages for the region (Figure 3). At the nearest weather station, precipitation was 123% of the normal 30-year average at the to start the 2003 growing season (March - May) but site rain gauges indicated slightly lower amounts of spring rainfall (~85%) than the average (Appendix A for site rain gauge data). The fall regrowth period of the experiment, September through November 2003, was particularly drier than normal years. The nearest weather station received 34.5% of 30-year average precipitation during this period while site rain gauges received only 44.4% of normal moisture. Total site precipitation for the 2002-2003 growing season (December to December) was 207 mm (67.4% of the PRISM model average).

Split plot level experimental units (untreated control, burn, imazapic-applied, and both burn and imazapic-applied plots) showed little to no difference in soil moisture

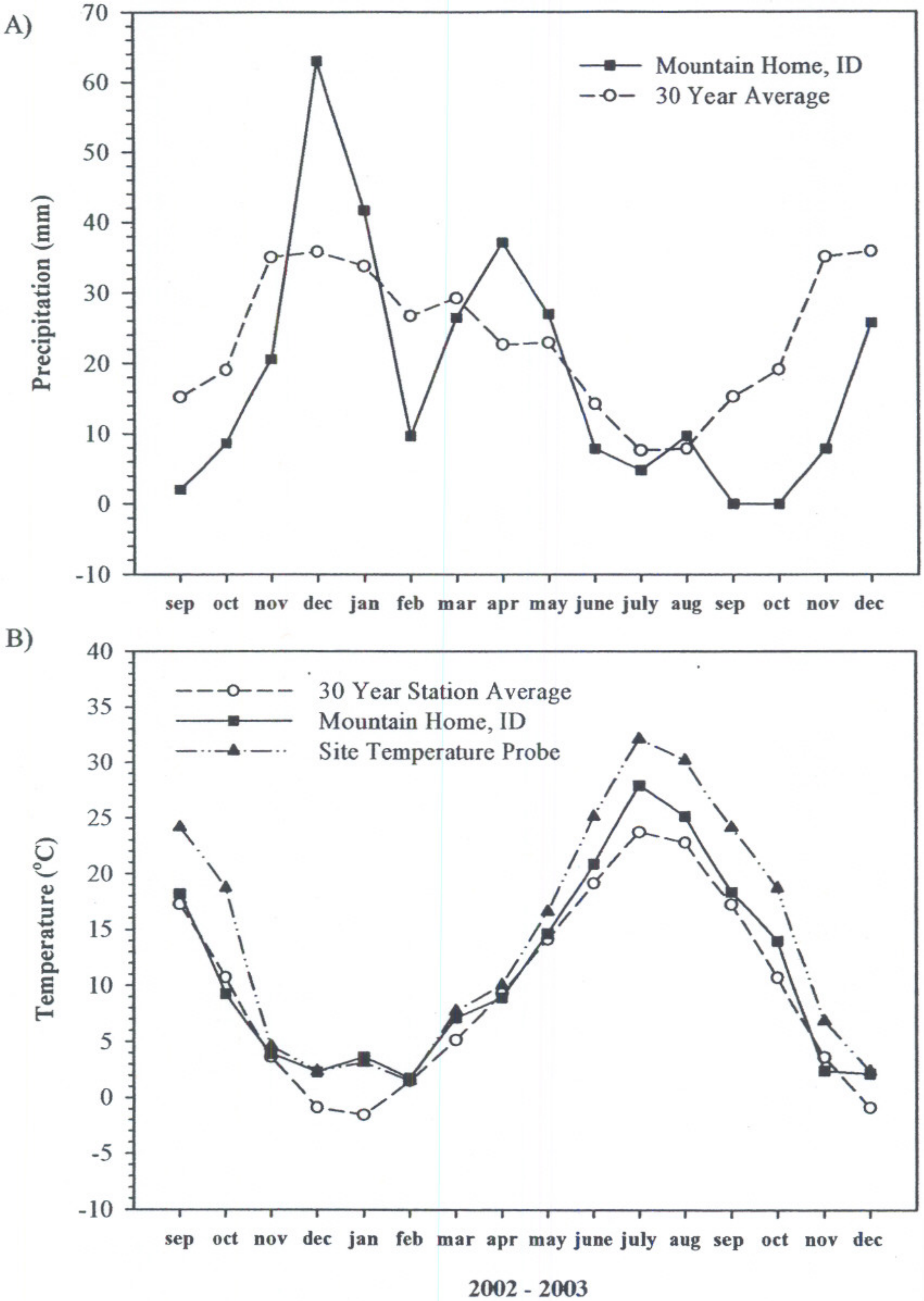

Figure 3. Average total monthly precipitation (A) and average monthly temperatures (B) for the study period from the nearest station (Mountain Home, ID, USA) and site temperature probe. (http://www.wrcc.dri.edu 20 Feb 2004).

10 cm below the surface throughout most of the experiment (Figure 4). One exception is later in the growing season (June – July) where herbicide plots had approximately 5-10% greater soil moisture. These seemingly ample growing conditions resulted in emergence of most species however *S. grossulariifolia* emergence was low (<1%) in all treatments. This species was thus omitted from all statistical analyses.

Imazapic application used alone did not reduce *B. tectorum* densities compared to controls (P=0.94), but it did reduce seed set by 73.3% (P<0.01, Figure 5). However, imazapic alone reduced densities of *T. caput-medusae* and its seed set by 89.1% (P<0.01) and 78.3% (P<0.01) respectively compared to controls. Manual weeding of *B. tectorum* and *T. caput-medusae* from February through April did progressively reduce weed densities with the removal of individual plants. Weeding reduced densities of *B. tectorum* by 69.6% (P<0.01) and *T. caput-medusae* by 82.8% (P<0.01) compared to unweeded control plots throughout the growing season. More specifically, weeding removed more *B. tectorum* plants than higher imazapic applications onto unburned areas (57.0%, P<0.01). Conversely, higher imazapic applications reduced more *T. caput-medusae* plants than hand weeding (58.4%, P=0.09). Higher imazapic applications alone also reduced *B. tectorum* and *T. caput-medusae* seed production compared to weeding (reductions of 74.0% (P<0.01) and 78.9% (P<0.01) respectively).

At the onset of the experiment, we assumed that the two rates of imazapic would be similar in their ability to reduce both exotic annual grasses. To test this expectation, we evaluated imazapic applications alone versus untreated controls and prescribed burning versus burning and imazapic applications to see if these treatments yielded similar reductions in invasive annual grasses. Herbicides applied to burned plots

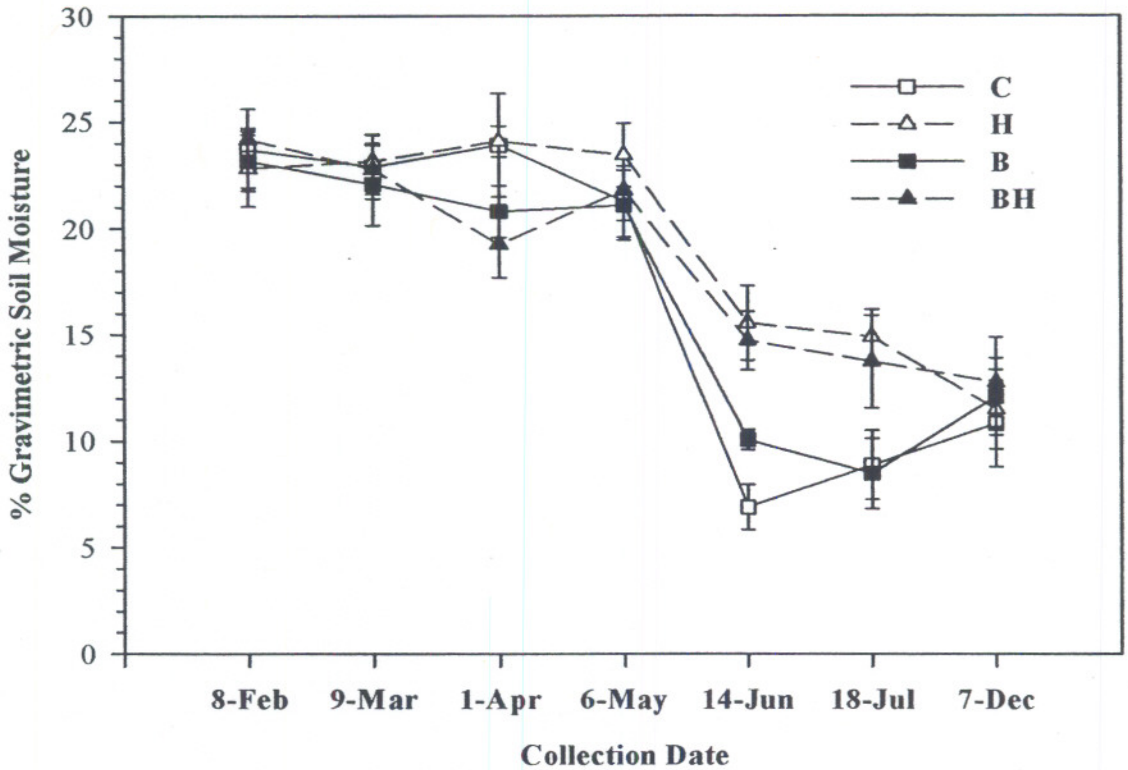

Figure 4. Percent gravimetric soil moisture (means ± SE) at the Canyon Creek study site throughout the entire study period by whole plot and subplot design factors. C = control, H = herbicide applied, and B = burned.

reduced 59% more *B. tectorum* plants and 6 % more *T. caput-medusae* plants than unburned herbicide applications. These differences translate into a reduction from 278 total annual weeds per m^2 using higher imazapic rates on unburned areas to 102 plants per m^2 in plots with lower imazapic rates onto burned areas. In addition, seed production varied with imazapic application rate, with higher rates of imazapic onto unburned areas reducing equal amounts of *B. tectorum* seeds per plant but almost 25% more *T. caput-medusae* seeds per plant than lower rates onto burned areas.

Because herbicide rates differed in their herbicidal effectiveness of annual grass control, with lower rates onto burned plots achieving better weed reduction, herbicide effects are nested within levels of burning and cannot be interpreted directly (See Appendices E through K for changes in ANOVA models for seedling establishment).

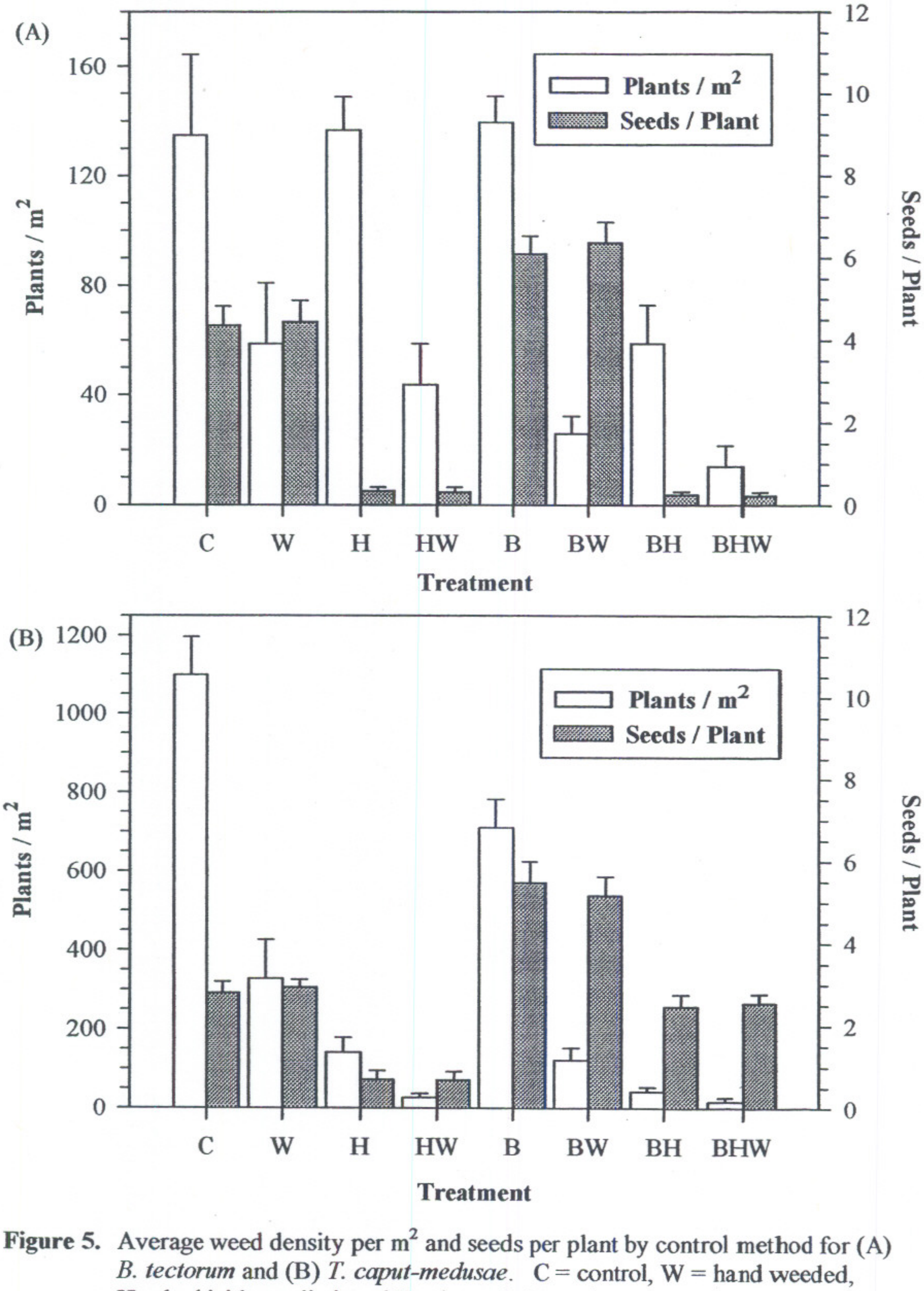

Figure 5. Average weed density per m^2 and seeds per plant by control method for (A) *B. tectorum* and (B) *T. caput-medusae*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Bars denote sample standard errors (± 1 SE).

***Elymus multisetus* (Sand Hollow squirreltail)**

Proportional emergence of *E. multisetus* was significantly greater in plots where imazapic alone was applied compared to all other treatments (three-way interaction of herbicide*weeded nested within burning; $P<0.001$), including plots that were simply weeded by hand (Figure 6). However, insufficient numbers of emerging *E. multisetus* seedlings were found in any treatment during the fall census period so end-of-season seedling density was not analyzed for this species.

The seedling emergence rate for *E. multisetus* differed separately in burning and weeding treatments ($P=0.006$ and $P=0.042$ respectively) (Figures 7A & B). Seedlings emerged nearly twice as early in unburned plots as in areas burned, but only slightly sooner in plots weeded of exotic annuals than nonweeded plots. Seeds sown in unburned plots treated with higher rates of imazapic emerged 1.7 times sooner than those in untreated controls ($P=0.020$) and in untreated burned plots ($P=0.017$), and 2.4 times sooner than seedlings from plots burned and treated with lower imazapic rates ($P<0.01$).

There were differences in rates of seedling mortality for *E. multisetus*, but only because of hand-weeding ($P=0.030$) (Figure 8A & B). Here, seedlings in weeded plots survived longer than those in nonweeded plots. A similar effect is also seen in treatment contrasts where herbicide applications onto both unburned and burned surfaces caused seedlings to die in nine-tenths the time than their corresponding hand-weeded plots ($P=0.036$ and $P=0.011$ respectively).

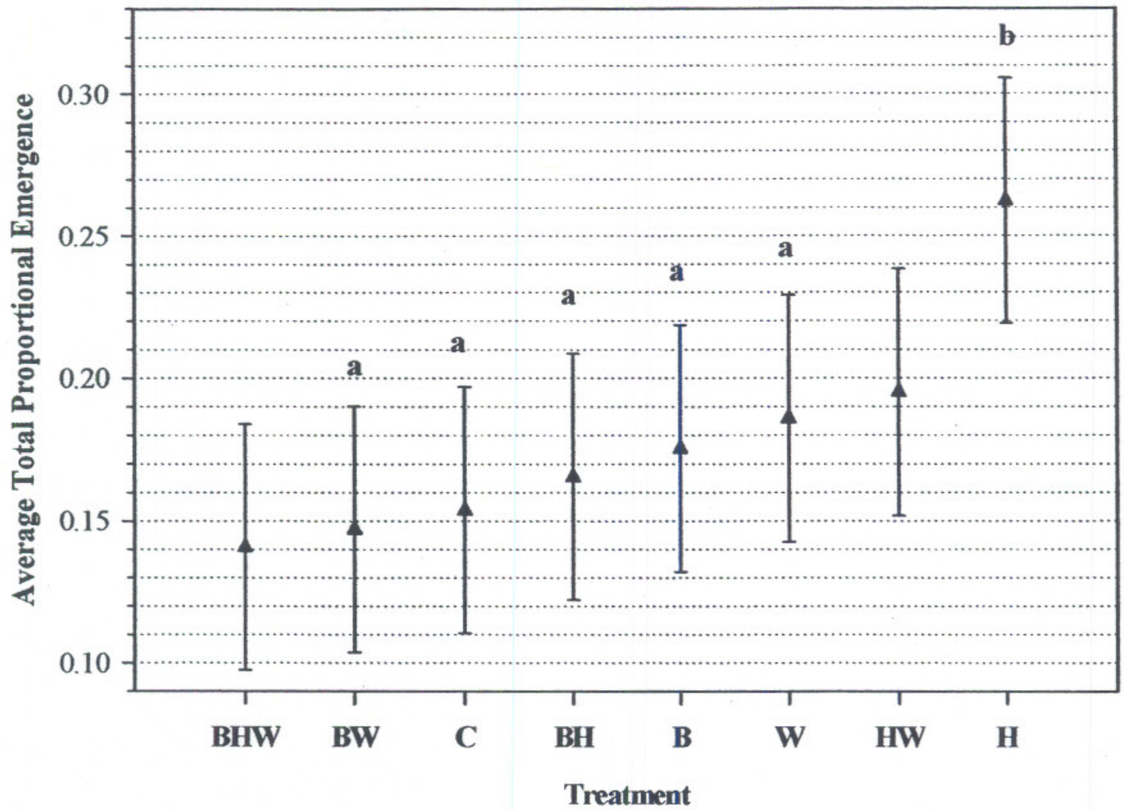

Figure 6. Average total proportional emergence for *Elymus multisetus* for each treatment (± 95% CIs). C = control, W = hand weeded, H = herbicide applied, and B = burned. Means involving the same lower case letter do not differ statistically at P=0.05. No contrasts of interest included treatments HW and BHW.

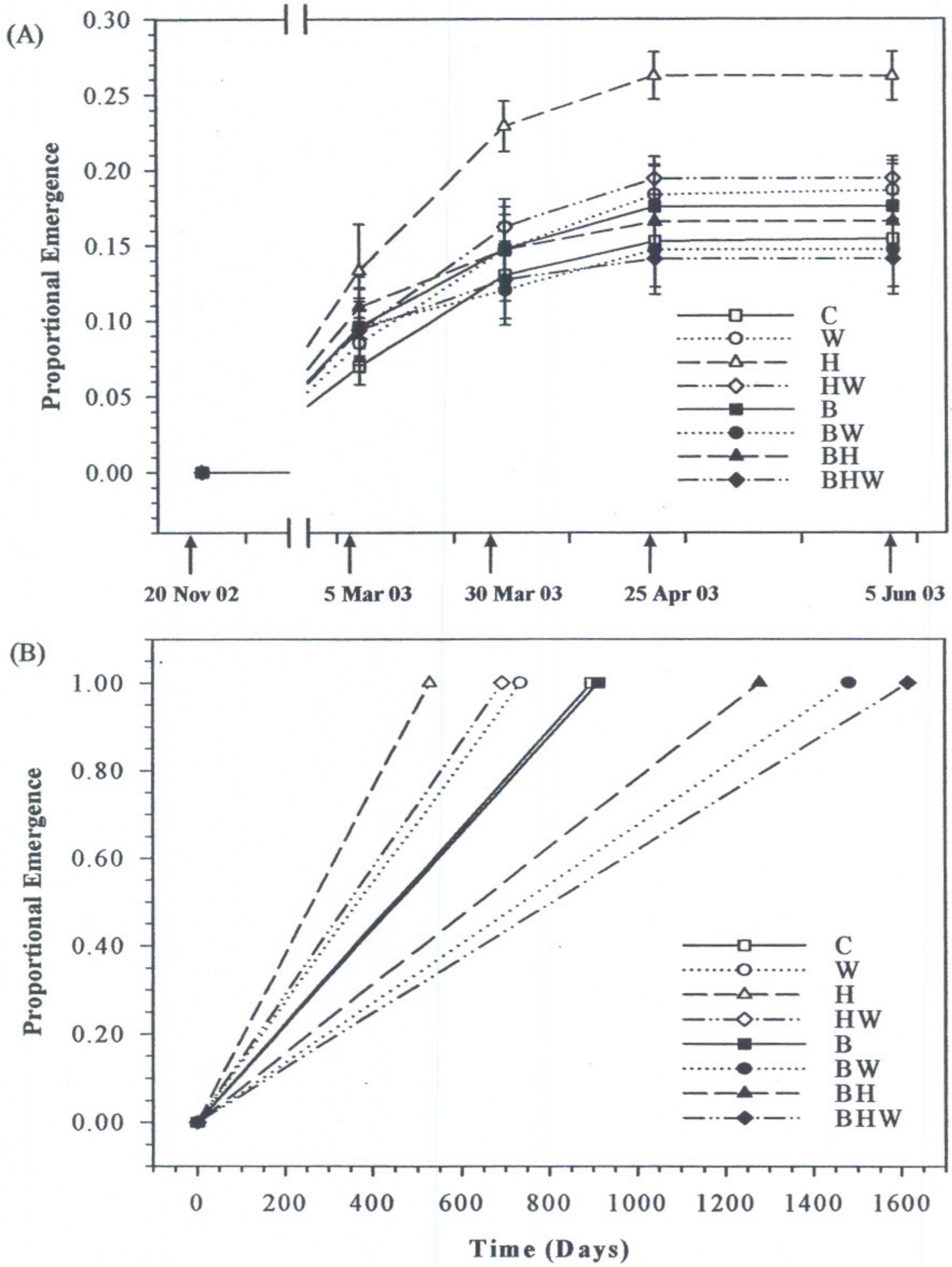

Figure 7. (A) Proportional emergence for each census period (dates with arrows) (means ± SE) and (B) Time to total emergence (as medians) for *E. multisetus*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 45 days in which seedling emergence began at some unknown time during winter 2003.

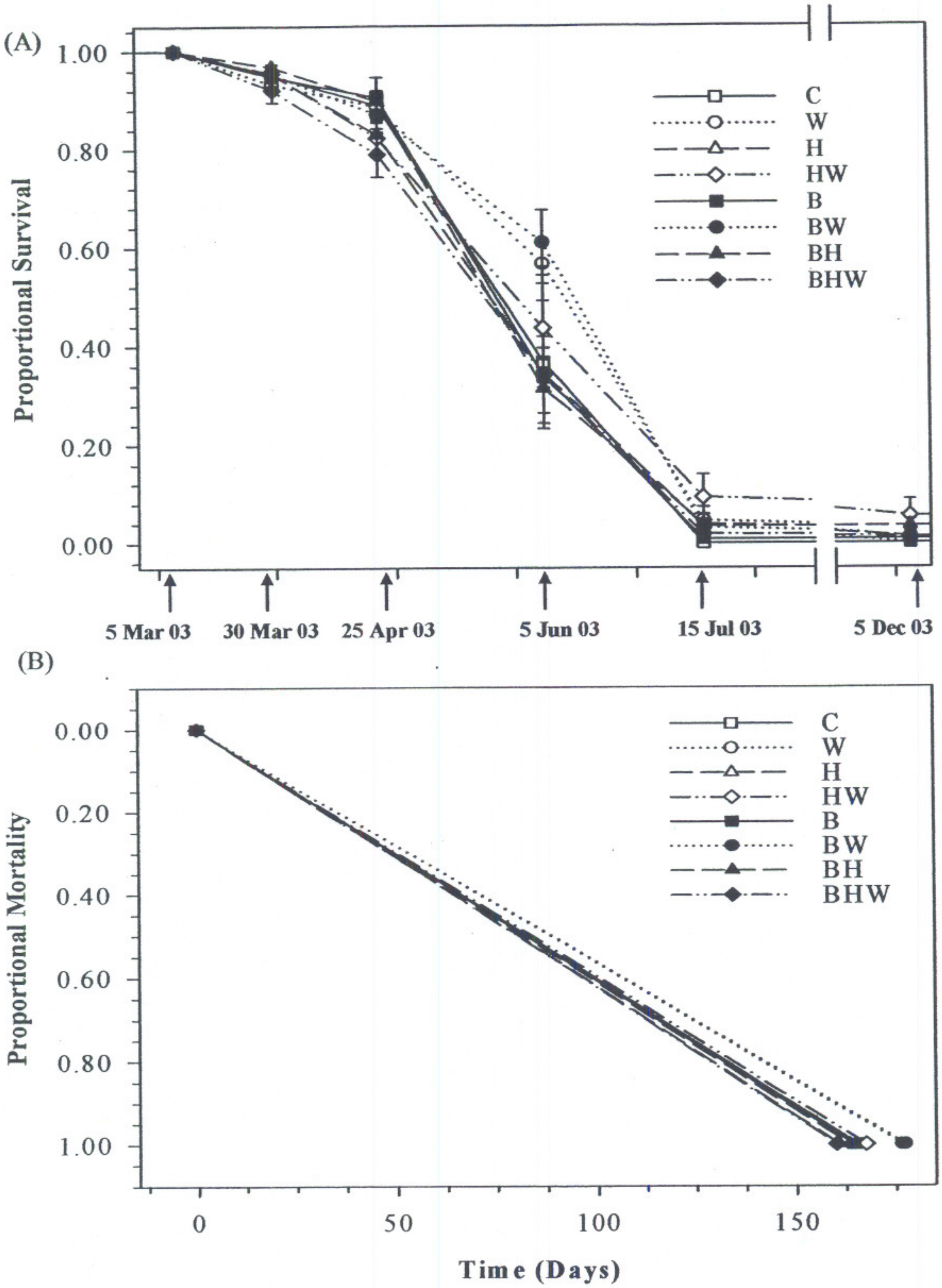

Figure 8. (A) Proportional survival (means ± SE) for each census period (dates with arrows) and (B) Time to total mortality (as medians) for *E. multisetus*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 60 days of fall 2003.

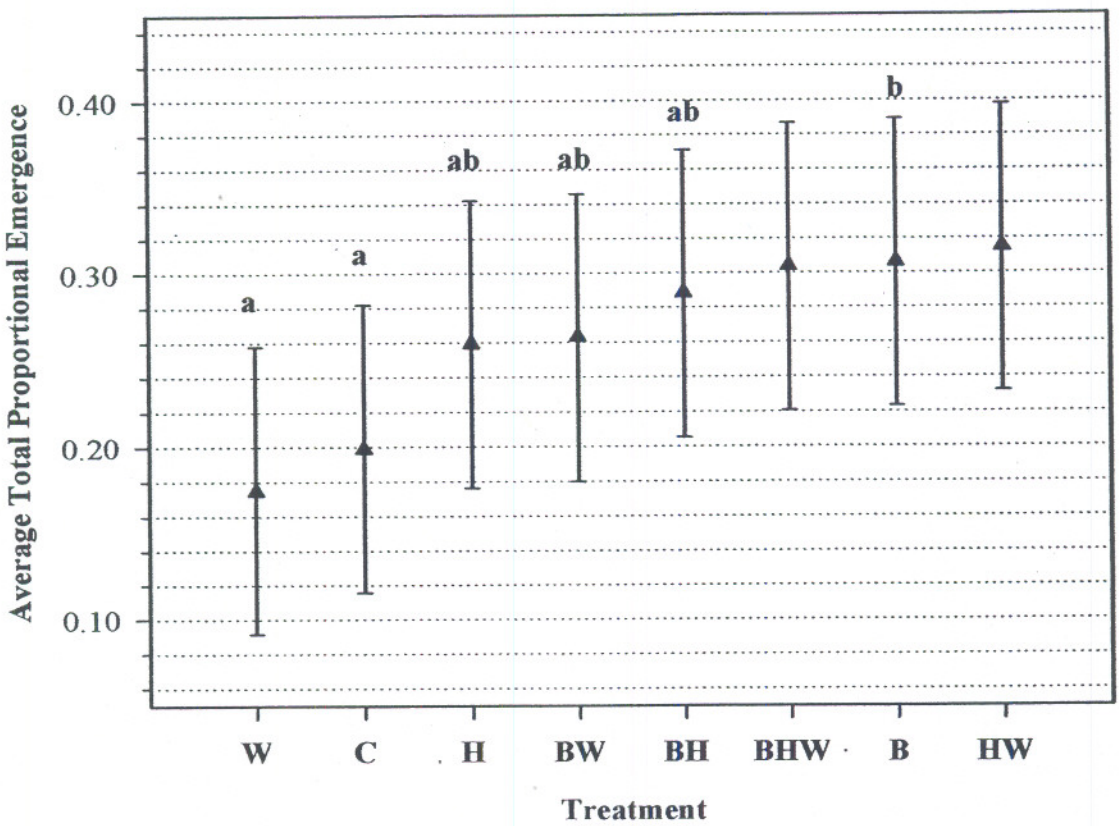

Figure 9. Average total proportional emergence for *Elymus wawawaiensis* for each treatment (± 95% CIs). C = control, W = hand weeded, H = herbicide applied, and B = burned. Means involving the same lower case letter do not differ statistically at P=0.05. Contrasts of interest did not include treatments HW and BHW.

Elymus wawawaiensis **(Secar Snake River wheatgrass)**

Imazapic and burning did affect total proportional seedling emergence of *E. wawawaiensis* (herbicide nested within burning; P=0.038) (Figure 9). For our specific contrasts of interest, only the untreated controls emerged fewer seedlings than plots that were only burned (P=0.050). Like *E. multisetus*, little fall regrowth of *E. wawawaiensis* seedlings occurred from those alive the previous spring so end-of-season survival of this species was not analyzed. No significant differences were found in the rates at which *E. wawawaiensis* seedlings emerged and/or persisted (P>0.072) (Figures 10 and 11).

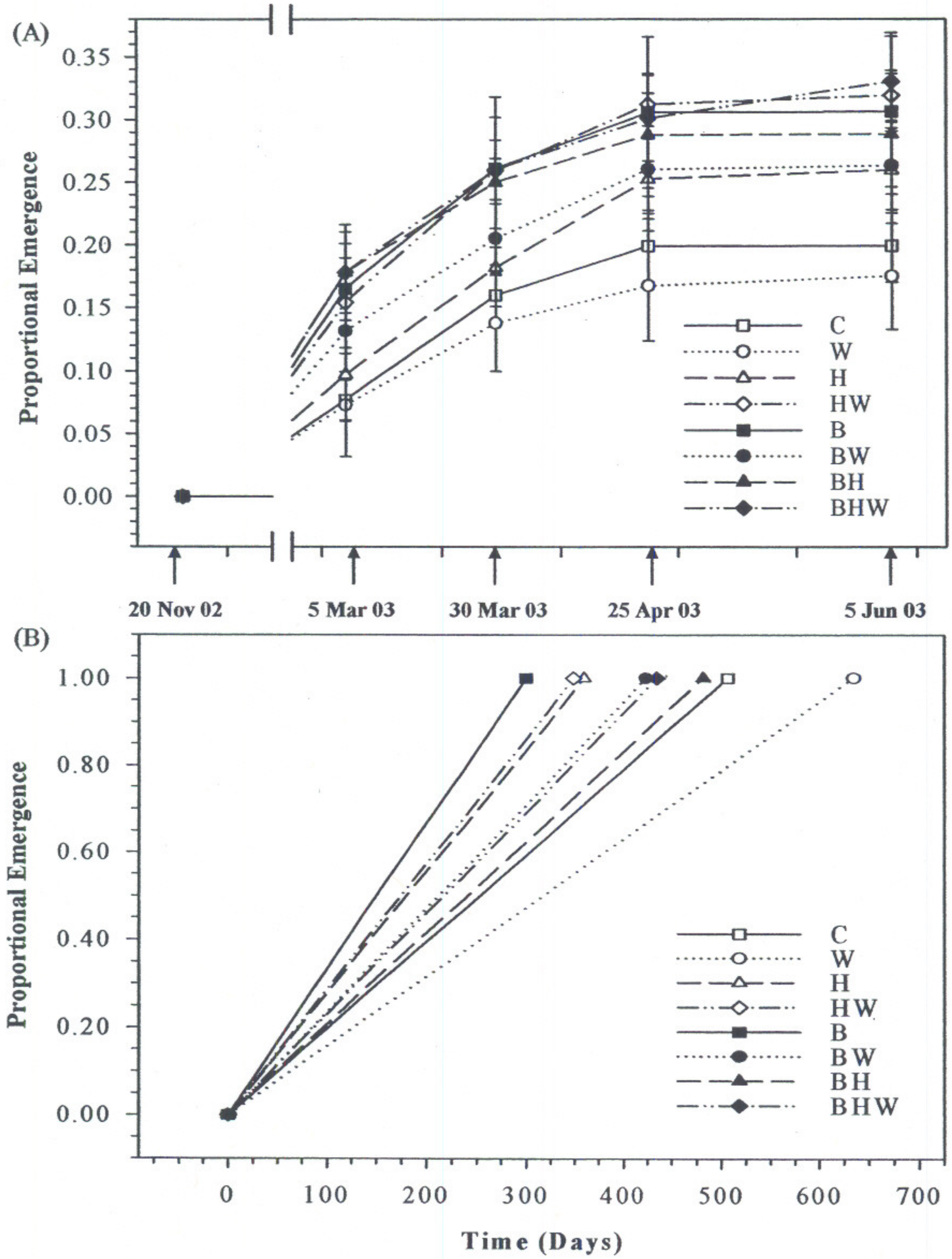

Figure 10. (A) Proportional emergence (means ± SE) for each census period (dates with arrows) and (B) Time to complete emergence (as medians) for *E. wawawaiensis*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 45 days in which seedling emergence began at some unknown time during winter 2003.

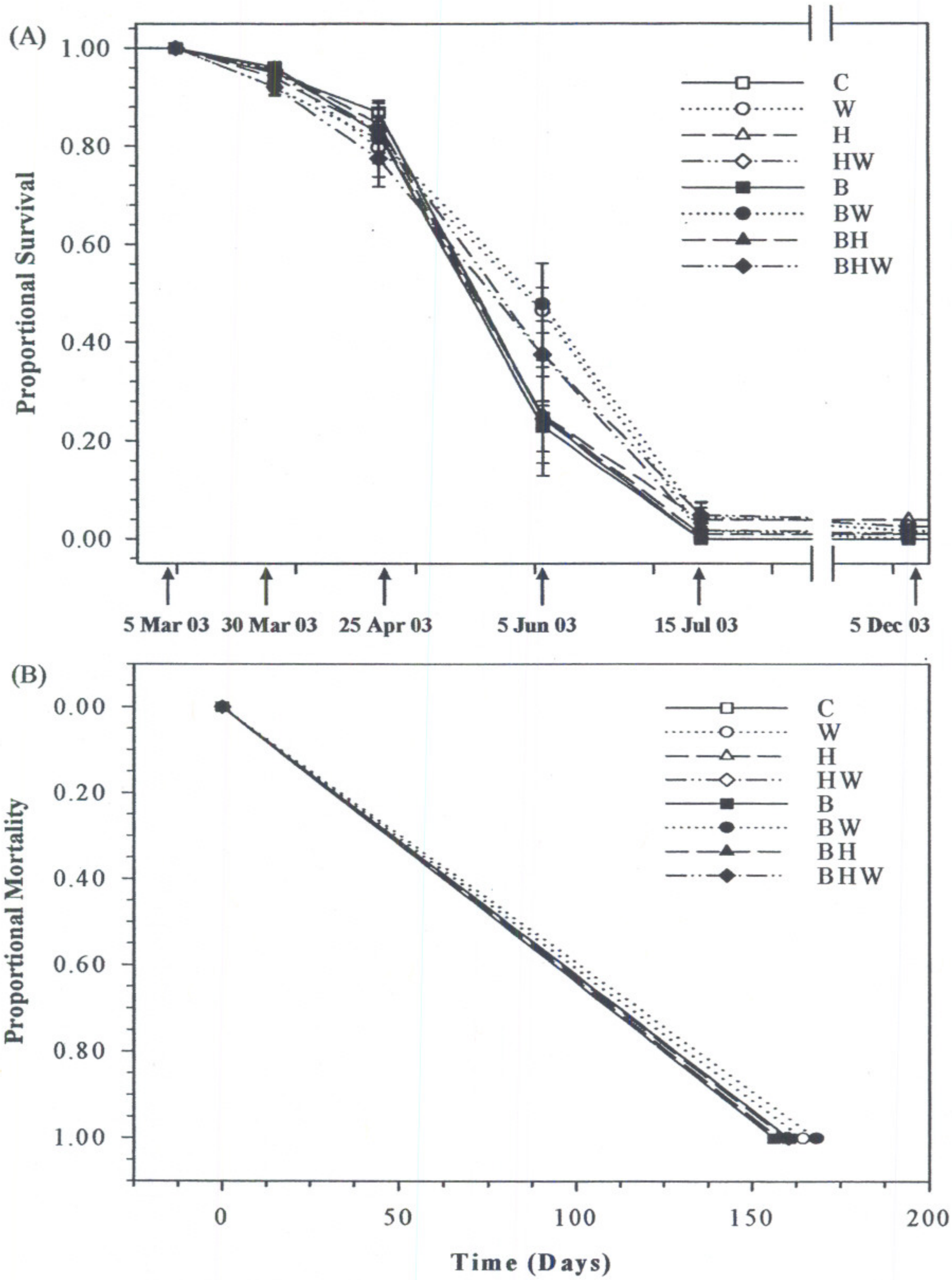

Figure 11. (A) Proportional survival (means ± SE) for each census period (dates with arrows) and (B) Time to total mortality (as medians) for *E. wawawaiensis*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 60 days of fall 2003.

***Artemisia tridentata* ssp. *wyomingensis* (Wyoming big sagebrush)**

Burning appeared to decrease proportional emergence of *A. tridentata*, but this effect was dependent on plots being manually weeded (burning by weeding interaction; P=0.039) (Figure 12). For particular treatment comparisons, prescribed burning alone and burning with lower rates of imazapic reduced total *A. tridentata* emergence compared to untreated controls (38.2% (P=0.004) and 36.1% (P=0.006) less, respectively). Prescribed burning alone and burning with lower rates of imazapic also reduced total emergence compared to higher rates of imazapic alone (28.2% (P=0.024) and 26.1% (P=0.035) less, respectively). Though total seedling emergence exceeded 35% for all treatments, too few *A. tridentata* seedlings survived to the fall census to allow for analysis of end-of-season seedling densities.

Burning was the only significant main effect (P=0.020) for emergence rates of *A. tridentata* seedlings. Seedlings in unburned treatments emerged an average 3.2 times sooner than burned treatments overall. This effect is apparent when looking at specific treatment comparisons and Figure 13 (A & B). *A. tridentata* seedlings in control plots emerged sooner than those in plots burned alone (5.2 times, P=0.006) and plots burned and treated with lower rates of imazapic (4.8 times, P=0.009). *A. tridentata* seedlings in plots treated with higher imazapic rates alone also emerged sooner than from plots burned alone (3.5 times, P=0.028) and plots burned and treated with lower imazapic rates (3.2 times, P=0.038).

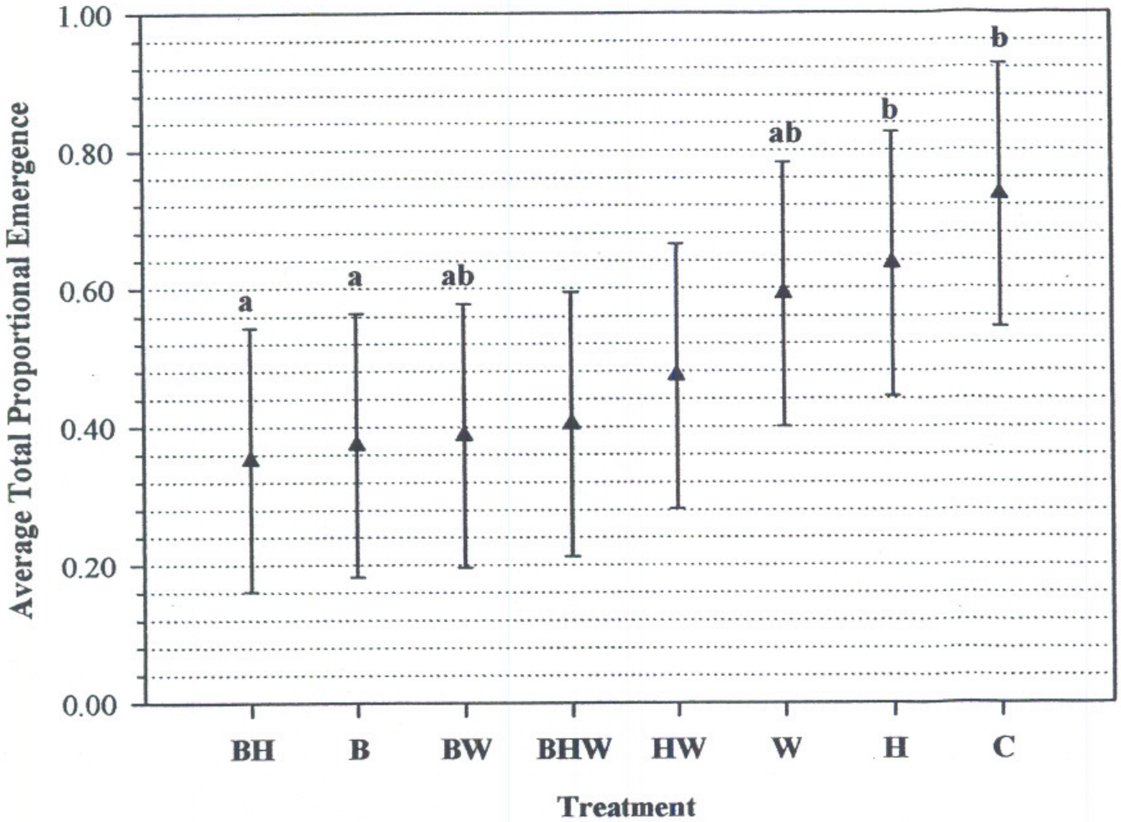

Figure 12. Average total proportional emergence for *Artemisia tridentata* ssp. *wyomingensis* for each treatment (± 95% CIs). C = control, W = hand weeded, H = herbicide applied, and B = burned. Means involving the same lower case letter do not differ statistically at P=0.05. No contrasts of interest included treatments HW and BHW.

Burning continued to be an important treatment effect with *A. tridentata* mortality (burning main effect at P=0.033) with seedlings dying faster in burned plots (Figure 14A & B). Specifically, plots that were burned and applied with lower rates of imazapic died in four-fifths the time than both untreated controls (P=0.012) and plots with higher rates of imazapic alone (P=0.019).

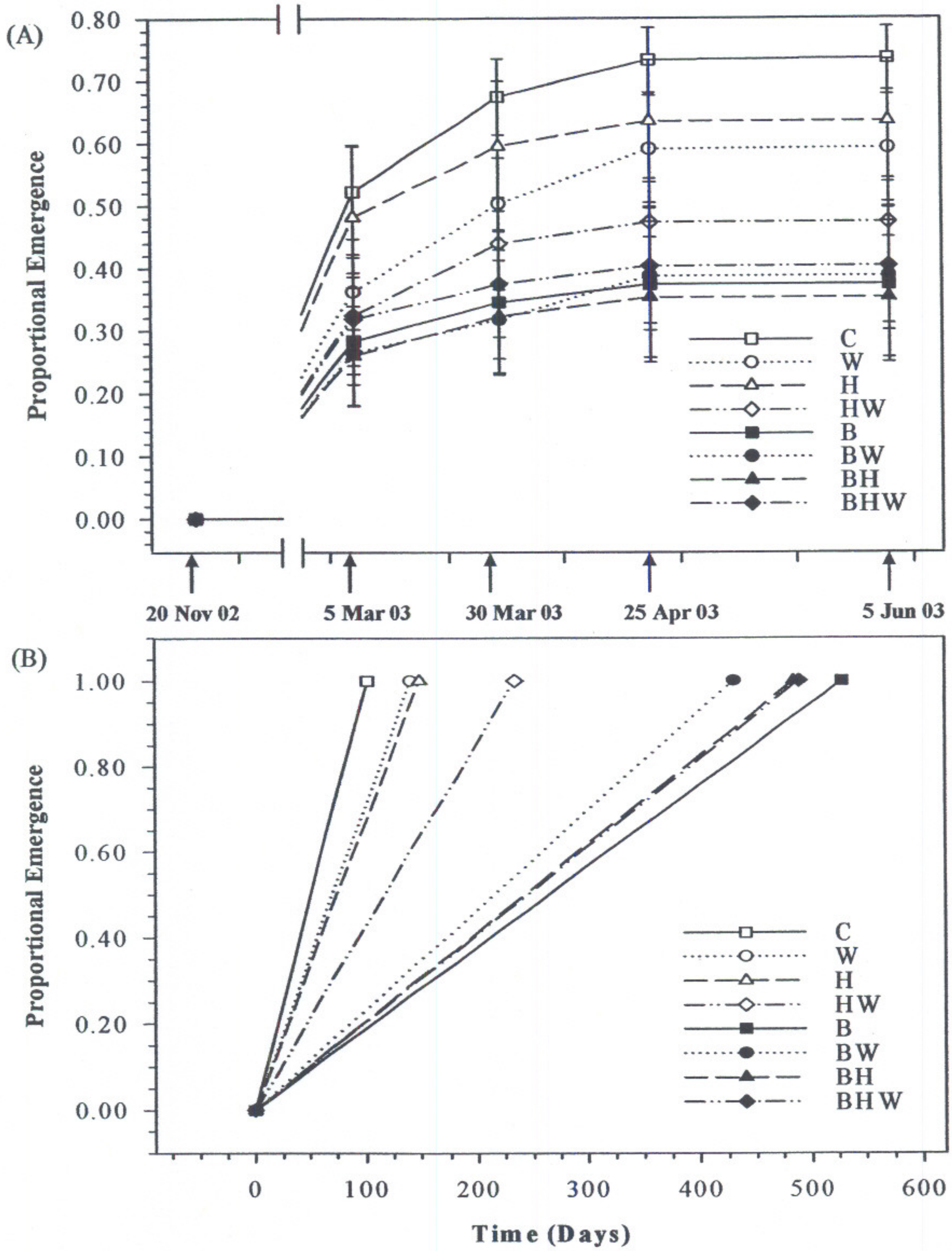

Figure 13. (A) Proportional emergence (means ± SE) for each census period (dates with arrows) and (B) Time to total emergence (as medians) for *A. tridentata* ssp. *wyomingensis*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 45 days in which seedling emergence began at some unknown time during winter 2003.

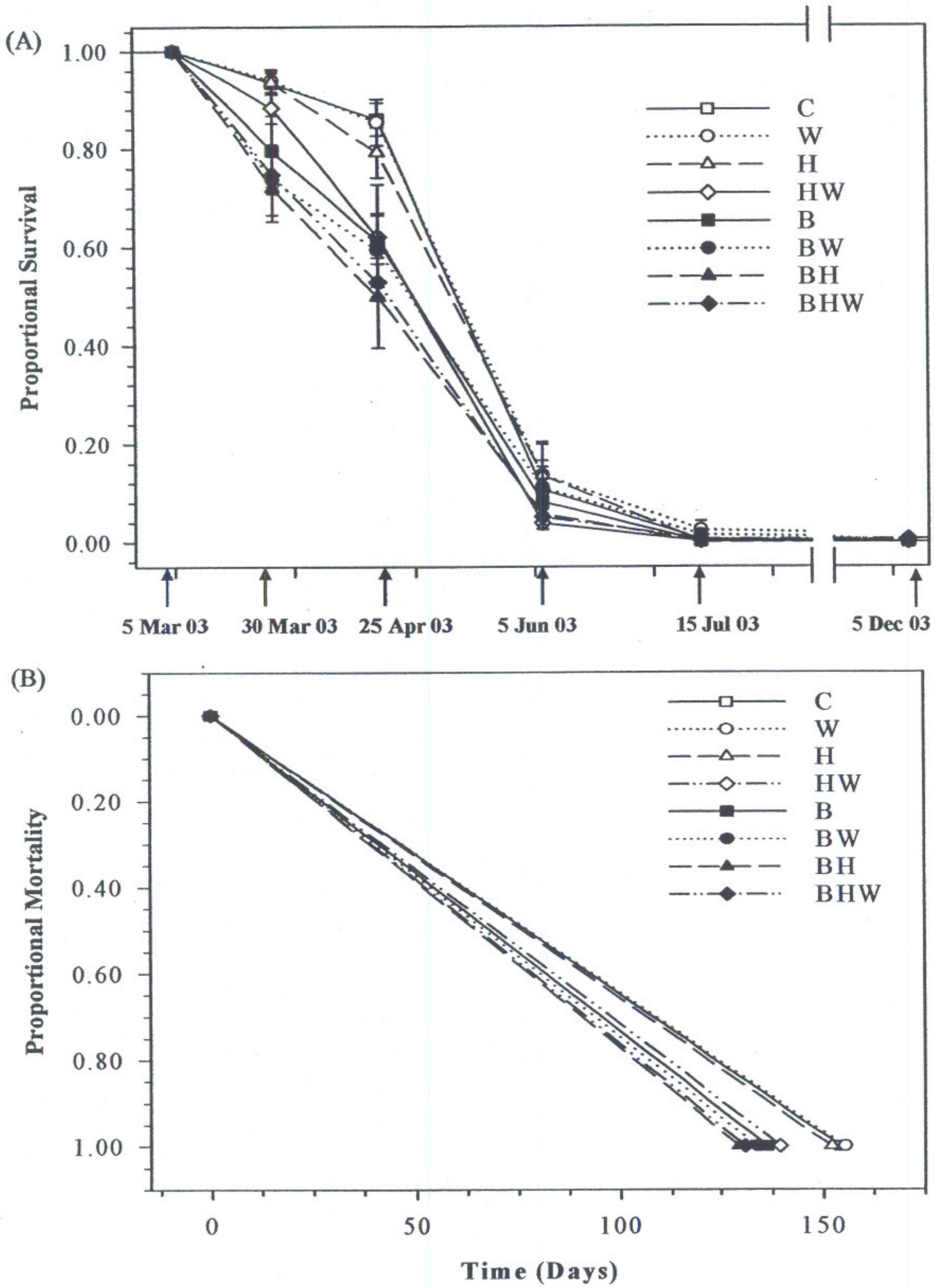

Figure 14. (A) Proportional survival (means ± SE) for each census period (dates with arrows) and (B) Time to complete mortality (as medians) for *A. tridentata* ssp. *wyomingensis*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 60 days of fall 2003.

***Achillea millefolium* (Great Northern western yarrow)**

Similar to *A. tridentata*, proportional seedling emergence of *A. millefolium* was affected by burning (burning main effect; P=0.016) (Figure 15). Unburned plots had 1.2 times more seedlings emerge than burned plots. As for particular treatment differences, more seedlings were located in both untreated controls (2.4 times, P=0.002) and higher imazapic applications alone (2.5 times, P=0.002) than in plots receiving burning and lower rates of imazapic. Despite at least 17% seedling emergence throughout the 2003 growing season, *A. millefolium*, like most other seeded natives, failed to provide sufficient fall survivors to be analyzed.

Burning affected *A. millefolium* emergence rates, with seedlings in unburned treatments emerging 2.2 times faster than unburned treatments (P=0.015) (Figure 16A & B). For contrasts of interest between treatments, untreated controls, burning alone, and plots with higher rates of imazapic alone all displayed quicker *A. millefolium* emergence than plots that were burned and applied with lower imazapic rates (4.1 times, P<0.001; 2.1 times, P=0.038; and 3.5 times; P=0.002; respectively).

Similar to rates of emergence, both burning and herbicide treatments affected rates of *A. millefolium* survival (herbicide within burning effect; P=0.010) (Figure 17A & B). For areas burned and applied with lower rates of imazapic, seedling deaths occurred in four-fifths the time compared to untreated controls (P=0.002) and higher rates of imazapic alone (P=0.002), and in nine-tenths the time compared to burning alone (P=0.004) and burning followed by hand-weeding (P=0.007).

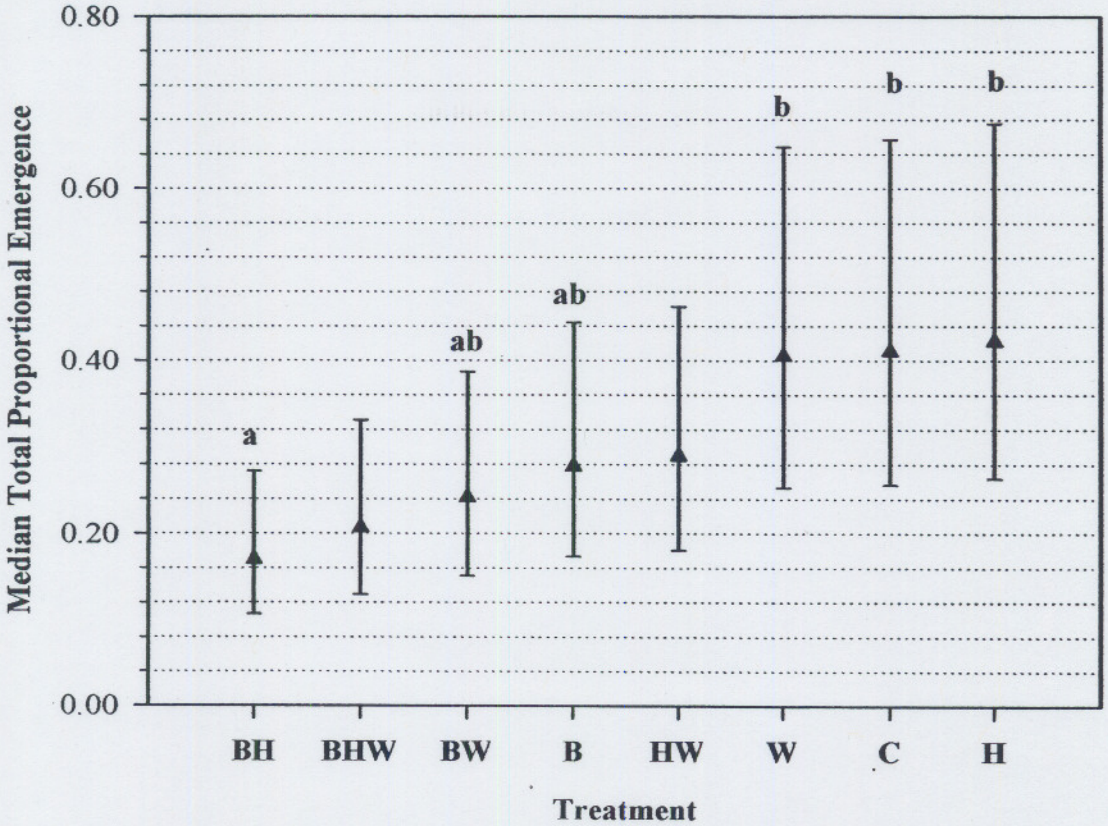

Figure 15. Median total proportional emergence for *Achillea millefolium* for each treatment (± 95% CIs). C = control, W = hand weeded, H = herbicide applied, and B = burned. Medians involving the same lower case letter do not differ statistically at p=0.05. No contrasts of interest included treatments HW and BHW.

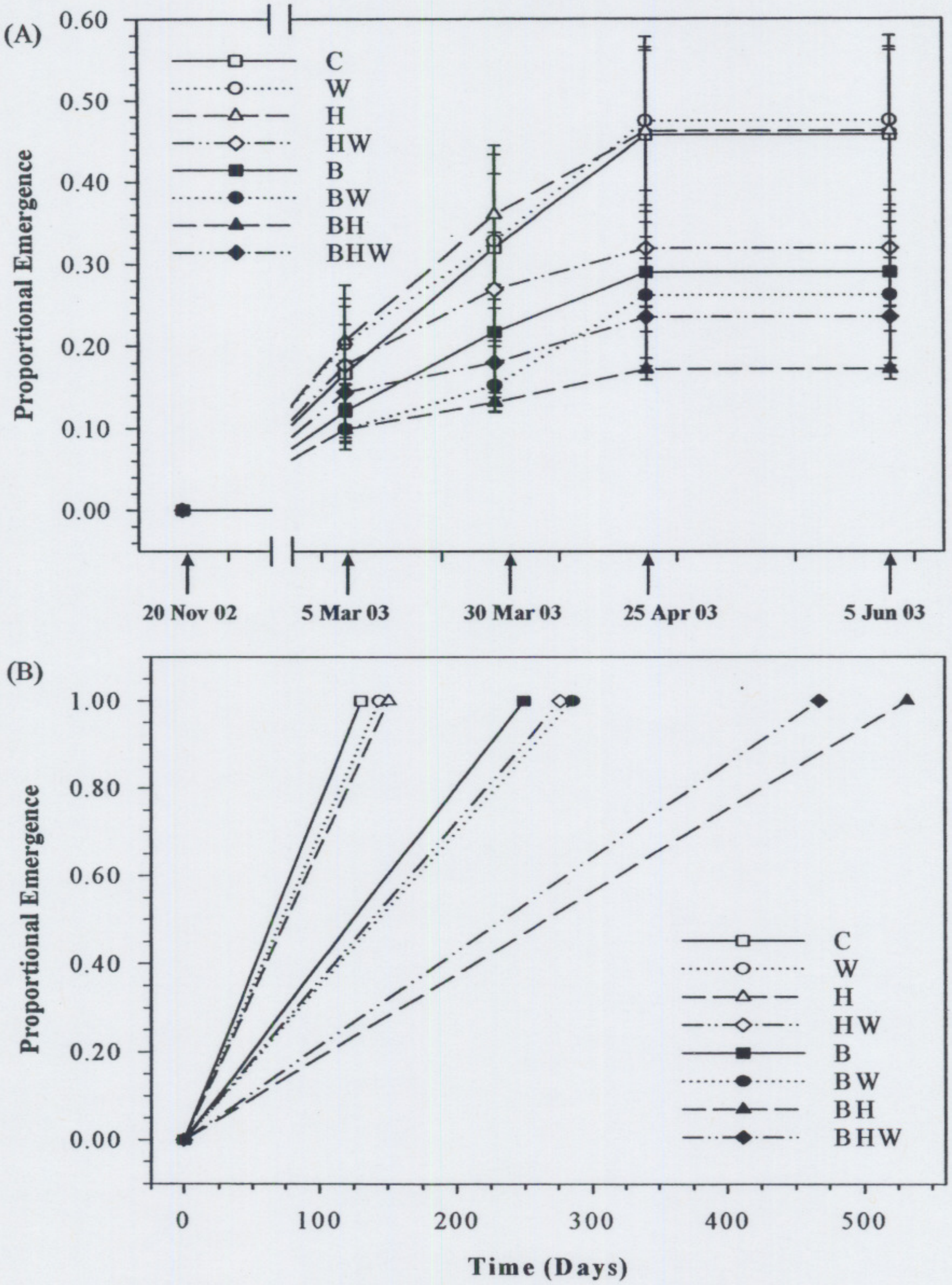

Figure 16. (A) Proportional emergence (means ± SE) for each census period (dates with arrows) and (B) Time to total emergence (as medians) for *A. millefolium*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 45 days in which seedling emergence began at some unknown time during winter 2003.

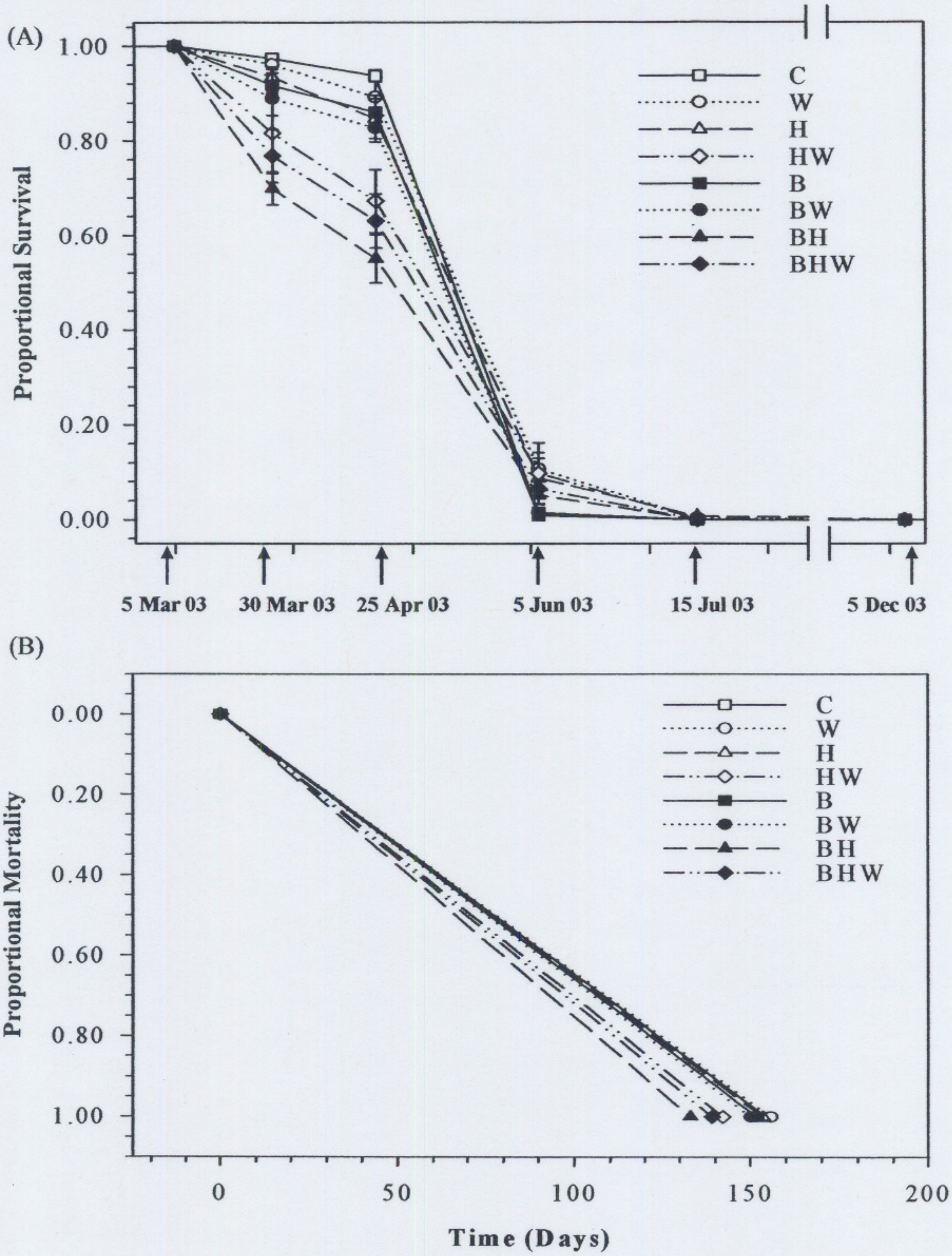

Figure 17. (A) Proportional survival (means ± SE) for each census period (dates with arrows) and (B) Time to total mortality (as medians) for *A. millefolium*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 60 days of fall 2003.

***Poa secunda* (High Plains Sandberg bluegrass)**

No statistical differences were found for the total proportional emergence of *P. secunda* seedlings (Figure 18A). A significant three-way interaction (herbicide by weeding within burning) did exist for the overall fall densities of these emerged plants (P=0.015). Of the tested contrasts, untreated controls produced 3.3 times more plants per m^2 than areas applied with higher rates of imazapic (P=0.027). Also, hand-weeding plots produced 5.7 times more plants per m^2 than areas applied with higher rates of imazapic (P=0.003) (Figure 18B).

Burning influenced the emergence rates of *P. secunda* seedlings (P=0.056) (Figure 19A & B) with seedlings emerging in unburned plots 1.4 times sooner than in burned plots. Seedling mortality rates, however, did not differ among treatments for *P. secunda* (Figure 20A & B).

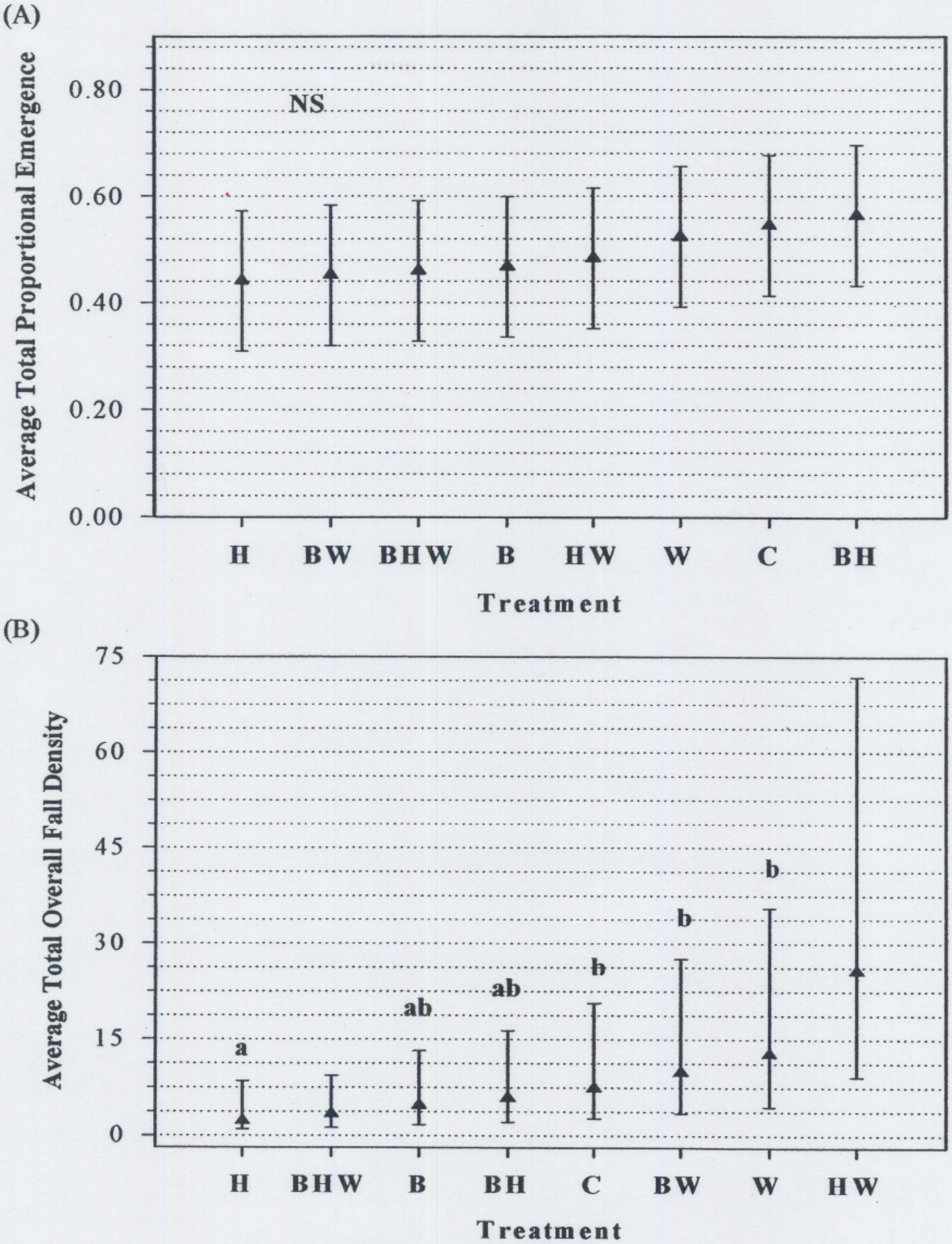

Figure 18. (A) Average total proportional emergence and (B) Overall fall density (as medians) for *Poa secunda* for each treatment (± 95% CIs). C = control, W = hand weeded, H = herbicide applied, and B = burned. NS indicates that no contrast of interest differs statistically at p=0.05. Medians involving the same lower case letter do not differ statistically at p=0.05. No contrasts of interest included treatments HW and BHW.

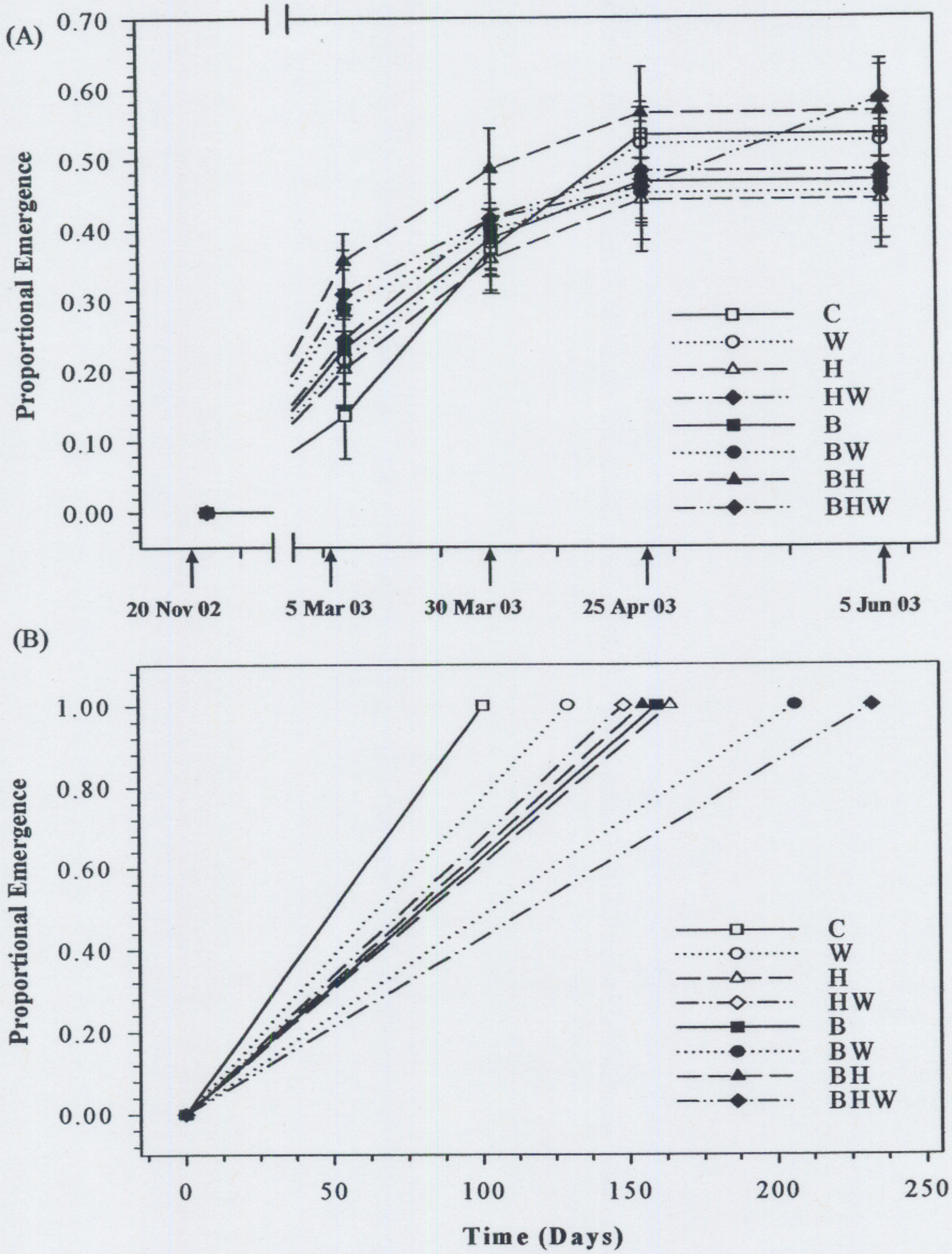

Figure 19. (A) Proportional emergence (means ± SE) for each census period (dates with arrows) and (B) Time to total emergence (as medians) for *P. secunda*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 45 days in which seedling emergence began at some unknown time during winter 2003.

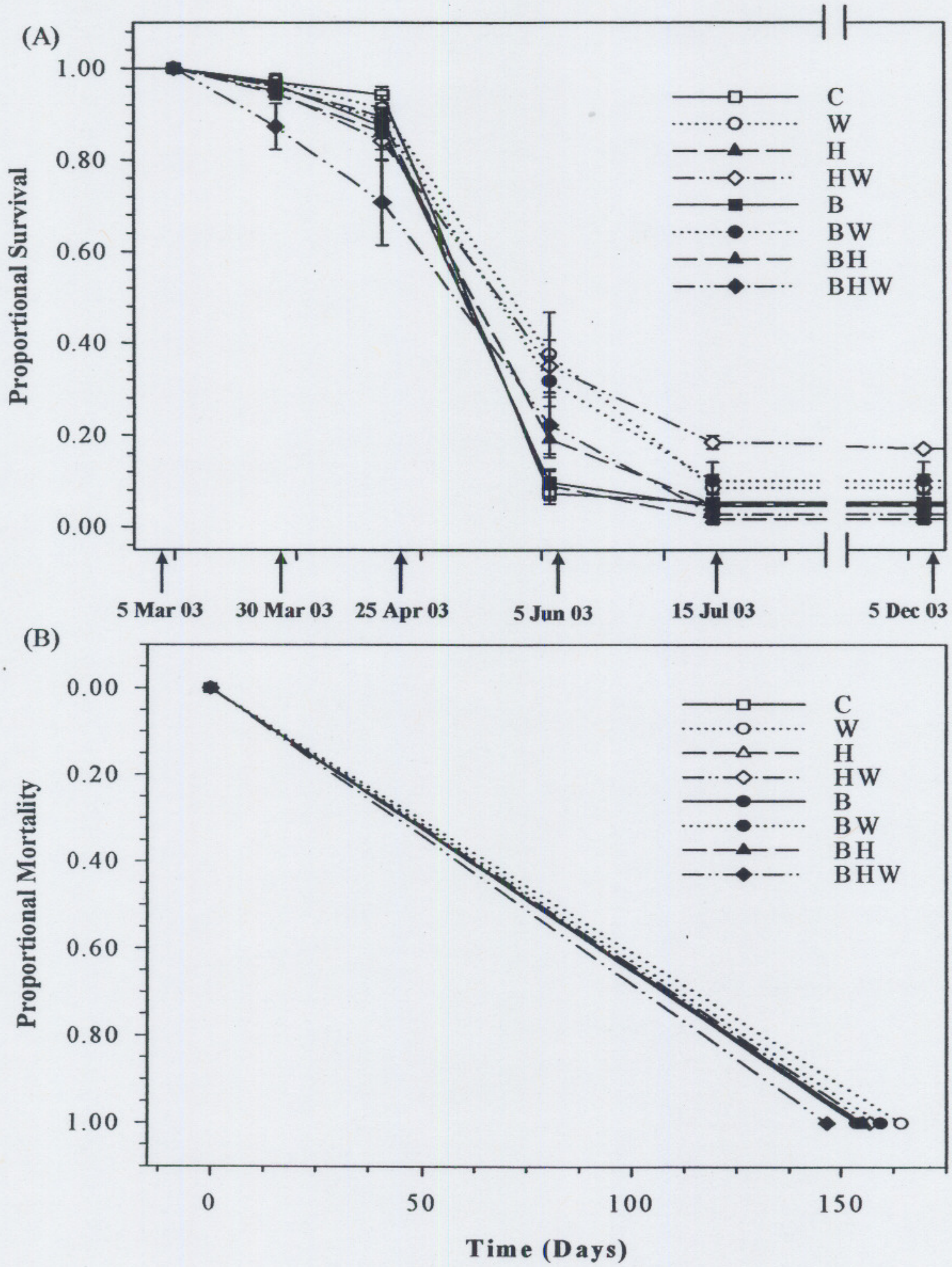

Figure 20. (A) Proportional survival (means ± SE) for each census period (dates with arrows) and (B) Time to total mortality (as medians) for *P. secunda*. C = control, W = hand weeded, H = herbicide applied, and B = burned. Axis break in (A) contains 45 days in which seedling emergence began at some unknown time during winter 2003.

DISCUSSION

Treatment Efficacy

One of the most common causes of revegetation failure in the Great Basin is the dominance of exotic annual grasses. This study reaffirmed studies by Peters and Bunting (1994) and Stubbs (2000) finding that prescribed burning alone will not sufficiently reduce *B. tectorum* and *T. caput-medusae* dominance. Although burning overall did slightly reduced densities of both weeds by physically burning seeds before germination, it was shown similar to Stubbs (2000) that surviving *T. caput-medusae* plants in burned plots benefit from these more open, fertile conditions producing three times more seeds than unburned areas.

This study verified that imazapic applications prior to emergence of exotic annual grasses can substantially reduce exotic annual grass dominance even at the two moderate herbicide rates chosen. Although seed production was greatly reduced for both grasses, density reductions were much greater for the dominant *T. caput-medusae* as a result of imazapic applications. Herbicides overall actually controlled slightly fewer seeds of *T. caput-medusae* plants than those of *B. tectorum* and this may relate to *T. caput-medusae*'s later phenologic development. Imazapic activity may have declined by the time surviving *T. caput-medusae* plants reached seed development, which averages 15-20 days later than *B. tectorum* (Hironaka 1994). Although higher imazapic rates were used to offset the effects of litter on herbicide penetration, the lower applications onto burned areas achieved better herbicide contact and greater overall weed control, particularly in the number of *B. tectorum* plants.

By removing weeds by hand, we attempted to reduce weed densities to that of using imazapic applications to isolate any herbicide effect from mere density effects. This isolation of an herbicide effect was seen in *T. caput-medusae* where densities were lower in imazapic-treated plots, but the density reduction did not result in higher seed production for surviving plants. We interpret this to mean that imazapic may be reducing *T. caput-medusae*'s ability to capture and use resources to produce seeds. This relationship was less obvious for *B. tectorum* because imazapic-induced density reductions were not apparent, but seed reductions per plant were observed. Highly crowded plants rather than herbicide effectiveness could be causing seed production to be lower in herbicide plots.

Native seedling tolerance to imazapic applications was defined as any instance when herbicide treatments established fewer seedlings compared to weeded or unweeded controls. This definition assumed that both herbicide and hand-weeded plots achieved the same degree of weed control and that all other experimental conditions were equal. Imazapic-treated plots, however, were more effective in reducing exotic annual dominance. Also, manual weeding may have physically disturbed seedbeds to the point of reducing native seed germination and subsequent establishment in these plots equal to that of any native intolerance to imazapic applications. Thus, only extreme reductions in seedling establishment in imazapic-treated plots were interpreted as species that were intolerant to the herbicide when compared to plots that were hand-weeded.

Trends in Native Seedling Establishment

This study indicates that although degree of weed control is known to be the primary regulator of seedling establishment of desirable plants in revegetation projects, other factors such as seasonal soil moisture, surface temperatures, litter cover, and early season herbicide bioavailability all play active roles in determining the fate of each seedling as the growing season progresses. Restoration species able to demonstrate early and aggressive capture of available resources will germinate, emerge, and survive in the face of competition from any uncontrolled annual weeds. Five native species emerged in this study but their seedling responses can be grouped into three structural/functional categories: deeper-rooted perennial grasses, native dicots, and shallow-rooted perennial grasses.

Deeper-rooted perennial grasses

Deeper-rooted perennial grasses are used extensively in restoration of Great Basin plant communities because they dominate ecosystems within this region and they occupy similar albeit not identical ecological niches as exotic annual grasses (Harris and Wilson 1970, Aguirre and Johnson 1991, and Arredondo et al. 1998). Even though Arredondo et al. (1998) reported equal growth rates for *E. elymoides, Pseudoroegneria spicata,* and *Agropyron cristatum* (crested wheatgrass) to that of *T. caput-medusae*, a weed-reduced environment may still be necessary for successful revegetation of most perennial grasses. In the current study, both *E. multisetus* and *E. wawawaiensis* showed positive responses in proportional emergence to imazapic treatments, suggesting some level of herbicide tolerance by both species. *E. multisetus* was particularly tolerant to weed-reduced conditions accomplished with higher rates of imazapic onto unburned areas. Although still greater than untreated controls, lower emergence of *E. multisetus* from plots applied with lower, burned rates of imazapic than from higher, unburned rates was unexpected. Even though burned and lower imazapic rates achieved greater weed control, *E. multisetus* may be less tolerant of these conditions. Overall, these trends support other studies that found *E. elymoides* (genetically similar to *E. multisetus*) successfully establishing in weed free conditions and thus, a potentially successful restoration species (Hironaka and Tisdale 1963, Hironaka and Sindelar 1973 and 1975; Young and Evans 1977, Jones 1998, and Clausnitzer et al. 1999).

A positive relationship has been reported between earlier emergence of natives and a higher probability of survival, where seedlings that germinate faster are more likely to utilize early season resources (Fowler 1988; Pyke 1990). These seedlings are then able to grow deeper roots in preparation for drier periods of the growing season. Early emergence was found only with *E. multisetus*, where seedlings emerged faster in unburned areas. This may have been due to surface litter that reduced evaporation, retained soil moisture, and moderated temperature extremes (Evans and Young 1987, Call and Roundy 1991).

In the Great Basin, summer dormancy causes the senescence of aboveground photosynthetic tissues of perennial grasses and perennating buds remain dormant until moisture resumes the following fall and winter. If there is adequate spring moisture and grass seedlings emerge quickly, sufficient belowground root growth may prolong their ability to maintain aboveground tissues. Although unburned treatments resulted in earlier emergence for *E. multisetus*, this greater performance did not extend the growing season for this deeper-rooted perennial grass.

Native Dicots

A. tridentata and *A. millefolium* were similar in their responses to the various applied treatments. These plants provided ample emergence during early spring 2003 when soil moisture was near field capacity in upper surface soil horizons. Reductions in total overall emergence in burned plots may have been due to burned areas being more exposed to extremes in surface temperature, frost heaving of the upper soil profile, and surface evaporation of available moisture. Studies of fire-tolerant species often show the opposite effect, with higher emergence in burned than unburned areas (Whelan and Main 1979; Purdie 1977). Since these two native species are not fire dependent, they may not tolerate fluctuating microclimate conditions. Seeds were most often sown under litter in unburned plots and this cover improved microsite conditions for emergence such as increased moisture retention and temperature regulation. Big sagebrush seeds are known to be particularly sensitive to the environmental conditions in which they are placed (Meyer 1992). Germinated dicot seeds were tolerant of higher rates of imazapic but are likely intolerant to conditions of burning and applying with lower rates of imazapic. For both native dicots, this burning with imazapic treatment, although achieving the greatest weed control, gave the lowest proportional emergence of all treatments. This outcome supports other determinations of native forb intolerance under certain levels of herbicide application. Washburn and Barnes (2000) found forb seedling emergence limited by 140 to 210 g ai/ha (2-3 oz/acre) of imazapic applied prior to native emergence. The imazapic label (PLATEAU® label. 2002. BASF Corporation, Research Triangle Park, NC, USA) also alludes to intolerance of certain forbs. For instance, gold yarrow (*A. filipendulina* Lam.), a dicot similar to *A. millefolium*, is identified as intolerant of preemergent herbicide applications.

Like deeper-rooted perennial grasses, early dicot seedling emergence could confer an advantage to longer overall survival. *A. tridentata* and *A. millefolium* emergence occurred faster in unburned plots perhaps again due to more stable temperatures and wetter conditions provided by the mulching effect of surface litter. Emergence of *A. millefolium* was particularly delayed in plots burned and applied with lower rates of imazapic compared to all other treatments including prescribed burning alone. This result implies that imazapic may slow seedling development of this species prior to emergence beyond mere burning effects.

Common to any emerged seedling in an area of seasonal and sporadic moisture, persistence and first year survival requires extensive root growth to maintain its stature throughout the summer dry period (Ries and Svejcar 1991). *A. tridentata* ssp. *wyomingensis* is well adapted to more xeric sites of the sagebrush biome, exhibiting larger root to shoot ratios early in the season than other *A. tridentata* subspecies to reach more perennial water sources deeper in the soil profile (Welch and Jacobson 1988, Booth et al. 1990). Unfortunately, early onset of dry conditions in June 2003 may have caused premature mortality of most native dicot seedlings because of their inadequate root growth. This mortality was then compounded for seedlings from burned plots that emerged later in the growing season.

Shallow-rooted perennials

Seedling responses of *P. secunda* can best be explained by its shallow-rooted structural / functional strategy. Just as many other natives tested, the rates of emergence and persistence of *P. secunda* were significantly affected due to prescribed burning because of the absence of litter effects.

According to Vallentine (1980), rangeland seeding success for a site with 10-12" of mean annual precipitation is defined by the number of plots that contain at least one plant per ft^2 (~ 11 plants per m^2). He provided the following rating system based on the number of seeded plots with sufficient first year plants: excellent (50% or more); good (40-50%); fair (25-40%); poor (10-25%); failure (10% or less). For *P. secunda*, the only seeded native with enough fall survival to rate its revegetation success, hand weeding and imazapic + hand weeding rated excellent; burning alone, burning + weeding, and burning + imazapic rated good; untreated controls and burning + imazapic + weeding rated poor; and imazapic alone rated as a failure. This indication of intolerance to single applications of herbicide onto unburned areas after one growing season follows results by Pellant et al. (1999), who found *P. secunda* plants adversely affected by a single spring application of OUST® (sulfometuron methyl), an herbicide with the same mode of action as PLATEAU®, as low as 70 g ai/ha (1 oz/acre). More research is obviously needed to assess fall survival of shallow-rooted perennial grasses.

Integrated Weed Management (IWM) Strategies

This study confirms a primary revegetation principle. Knowledge of seasonal emergence times and patterns of early survival are critical for sound revegetation attempts. It is important we understand that native seedling establishment is generally less dependent on the germination of seeds than it is on the environmental stresses that follow (Osmond et al. 1980). Regardless of applied treatment, inadequate soil moisture will limit the development of root systems capable of supporting young plants through later periods of lower moisture conditions. This study showed that this effect is exacerbated if seedlings are native dicots and if seedlings are forced to emerge later in the growing season. *P. secunda* was probably able to overcome deficiencies in both late spring and early fall precipitation because of its shallow, adventitious rooting depth and physiology. With more roots at the surface, smaller stature, and early phenology, this species may have been able to better utilize smaller amounts of precipitation for growth.

It is unclear how well the four species other than *P. secunda* would have survived if given higher levels of late spring and early fall precipitation. Several historic observational studies (Hull and Stewart 1948 and Harris 1967) have found successful first year establishment of deeper-rooted perennial grasses in the first year despite significant weed competition. These studies showed that *B. tectorum* densities as low as 90 and 100 plants/m^2 can limit bluebunch wheatgrass (*P. spicata*) and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) seedling survival to 20 to 40% of spring emergence. However, Hironaka and Sindelar (1973) reported *E. elymoides* establishment of at least 1 plant/ft^2, a revegetation success according to Vallentine (1980), at three of five range sites with medusahead densities up to 40 plants/ft^2 (~ 430 plants/m^2). In this study, only two treatments, untreated controls and burned plots, maintained mean weed densities greater than 430 plants/m^2, at 1,230 and 850 plants/m^2 respectively. It is likely that these treatments would not achieve desired revegetation objectives using deeper-rooted perennials regardless of proper precipitation. Only three treatments, burning + imazapic, imazapic + hand weeding, and burning + imazapic + weeding, lowered weed densities below 100 plants/ m^2 so fall survival of perennial grasses may have been greatest in these treatments. Fortunately, further reductions in survival due to herbicides after summer dormancy are unlikely because herbicidal activity is extremely low one year post seeding. Unfortunately, prior research is not available on the persistence of native dicots, similar to those used in this study, in annual grass stands.

Selecting an appropriate IWM strategy requires that we use experimental results to decide which imposed treatment optimizes the greatest weed control, greatest proportional emergence, earliest establishment, best seedling condition, and longest survival and greatest overall seedling densities at study completion for each of the six seeded natives. Although hand-weeding was used to isolate experimental treatment effects and may have resulted in or contributed to the best seedling establishment for some species, it would never be used on a larger scale to achieve aridland restoration objectives. Looking at treatment contrasts generated for all native species for each seedling establishment parameter, eight were found to have at least one significant treatment difference between two weed control treatments. All eight contrasts found lower imazapic rates on burned areas deficient in some seedling establishment parameter. This treatment would therefore be a poor strategy overall to achieve restoration on rangelands similar to the one studied, at least at the rate chosen for application. It would be difficult to make one IWM recommendation from the remaining three treatments (burning, imazapic alone, or controls) for all native species. Higher applications of imazapic onto litter outperformed untreated controls in only one instance, that of *E. multisetus* emergence, so this single treatment might be used when attempting revegetation of this species. Contrary to expectations, no reduction in any seedling parameter was found using higher rates of imazapic on unburned areas compared to untreated controls for species *E. wawawaiensis*, *A. tridentata*, and *A. millefolium*. This finding would give some weight to the value of using imazapic on unburned areas for future seedbed preparations.

While this is only one study, in one year and one location, we believe this approach has merit for examining these new IWM treatment strategies. More research is needed on arid rangelands using imazapic as part of an IWM strategy where native plant restoration is the goal. This study is one of the first to use autumn imazapic applications as a preemergent to control exotic annual grasses followed immediately by a planting of native seeds. Because other northern Great Basin imazapic studies (Shinn and Thill 2004) found that perennial grasses are injured with spring applications, research must continue to use these fall applications to allow herbicide activity to subside before natives emerge. Once a full complement of Great Basin natives with a range of structural/functional strategies are discovered tolerant to imazapic and other similar preemergent herbicides, Great Basin revegetation efforts can and will be widely successful.

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APPENDICES

Appendix A. Ambient Site Weather Measurements.

Canyon Creek Rain Gauge Summary:
Date Installed: 14-Sept-02

Recorded Range	Gauge #1 (mm)	Gauge #2 (mm)	Gauge AVE (mm)	Station AVE (mm)	30 Year AVE (mm)
14-Sep-02 - 14-Dec-02	89.00	94.00	91.50	61.72	79.63
14-Dec-02 - 08-Feb-03	85.50	98.00	91.75	73.15	58.36
08-Feb-03 - 05-Mar-03	7.50	8.00	7.80	9.65	24.87
05-Mar-03 - 03-Apr-03	19.00	22.00	20.50	26.42	29.21
03-Apr-03 - 05-May-03	27.00	30.00	28.50	37.08	22.60
05-May-03 - 14-Jun-03	19.00	17.00	18.00	30.86	29.97
14-Jun-03 - 17-Jul-03	7.00	5.00	6.00	6.35	10.92
17-Jul-03 - 11-Nov-03	11.00	8.00	9.50	9.97	57.65
11-Nov-03 - 07-Dec-03	23.00	27.00	25.00	7.87	32.31
Totals					
14-Dec-02 - 07-Dec-03			207.05	201.36	265.89
			8.15"	7.93"	10.47"

Canyon Creek Temperature Probe Summary:
Date Installed: 24-Nov-02 / 05-Mar-03

Month Recorded	AVE Soil Temp (°C)	AVE Air Temp (°C)	Station AVE Air Temp (°C)	30 Year AVE Air Temp (°C)
November	2.15	4.59	3.93	2.78
December	1.17	2.36	2.31	-1.50
January	2.91	3.15	3.64	-1.44
February*	---	---	1.76	1.72
March	7.43	7.75	7.13	5.58
April	7.84	10.05	8.94	9.44
May	13.41	16.61	14.67	14.06
June	19.68	25.15	20.86	19.03
July	26.87	32.12	27.74	23.33
August	24.32	30.22	25.56	22.83
September	17.89	24.15	18.53	17.17
October	12.90	18.72	14.34	10.44
November	1.60	6.86	2.32	2.78

* probe lost soil temperature connection - reestablished March 2003.

Appendix B. Prescribed Fire Fuels and % Moisture Content (MC).

Dates collected: 10/28/02 - 10/31/02

Plot	Preburn Date	preburn (g)	Post Date	postburn (g)	% Consumed
1	28-Oct	10.643	29-Oct	4.669	
1	28-Oct	10.511	29-Oct	10.258	
1	28-Oct	14.129	29-Oct	8.865	
1	28-Oct	13.667	31-Oct	4.791	
1	28-Oct	13.373	31-Oct	8.652	
8	28-Oct	15.596	29-Oct	10.731	
8	28-Oct	9.227	29-Oct	7.712	
8	28-Oct	20.624	29-Oct	5.625	
8	28-Oct	17.501	31-Oct	9.677	
8	28-Oct	12.431	31-Oct	3.621	
	mean	**13.77**	**mean**	**7.46**	**45.82**
	ste	**1.09**	**ste**	**0.82**	
3	28-Oct	12.055	30-Oct	2.392	
3	28-Oct	20.006	30-Oct	3.447	
3	28-Oct	20.440	30-Oct	5.627	
3	28-Oct	12.379	31-Oct	9.384	
3	28-Oct	9.661	31-Oct	7.153	
	mean	**14.91**	**mean**	**5.60**	**62.44**
	ste	**2.22**	**ste**	**1.26**	
6	28-Oct	18.161	30-Oct	6.875	
6	28-Oct	16.472	30-Oct	4.300	
6	28-Oct	14.670	30-Oct	7.753	
6	28-Oct	12.664	31-Oct	14.336	
6	28-Oct	21.236	31-Oct	7.840	
	mean	**16.64**	**mean**	**8.22**	**50.60**
	ste	**1.47**	**ste**	**1.66**	
9	28-Oct	12.081	29-Oct	7.398	
9	28-Oct	28.241	29-Oct	6.596	
9	28-Oct	16.783	29-Oct	4.581	
9	28-Oct	8.083	31-Oct	8.842	
9	28-Oct	12.542	31-Oct	3.264	
	mean	**15.55**	**mean**	**6.14**	**60.51**
	ste	**3.46**	**ste**	**1.00**	

Date collected: 10/29/02

Plot	pre dried (g)	post dried (g)	Difference	% MC		
1	21.473	20.600	0.873	4.066		
1	20.953	20.170	0.783	3.737		
8	23.182	22.200	0.982	4.236	**mean**	**4.03**
8	22.991	22.050	0.941	4.093	**ste**	**0.11**
9	18.303	17.710	0.593	3.240	**mean**	**2.91**
9	23.016	22.420	0.596	2.590	**ste**	**0.23**
3	22.948	22.050	0.898	3.913	**mean**	**3.80**
3	20.587	19.830	0.757	3.677	**ste**	**0.08**
6	21.750	20.900	0.850	3.908	**mean**	**3.89**
6	22.075	21.220	0.855	3.873	**ste**	**0.01**

Appendix C. % Gravimetric Soil Moisture by Treatment by Date.

Date collected: 02/08/03

Treatment*	Macroplot #	wet soil (g)	dry soil (g)	% Grav moisture		
C	2	52.877	43.862	20.553		
C	4	58.233	48.648	19.703		
C	5	50.958	40.030	27.300		
C	7	53.501	41.386	29.273	**Mean**	**23.692**
C	10	55.937	45.988	21.634	**STE**	**1.926**
H	2	51.284	40.590	26.346		
H	4	55.815	45.380	22.995		
H	5	51.957	41.005	26.709		
H	7	52.345	44.611	17.337	**Mean**	**22.808**
H	10	52.137	43.212	20.654	**STE**	**1.766**
B	1	58.233	47.220	23.323		
B	3	53.027	42.106	25.937		
B	6	51.304	41.058	24.955		
B	8	50.763	41.322	22.847	**Mean**	**23.155**
B	9	52.057	43.852	18.711	**STE**	**1.242**
B / H	1	54.308	43.588	24.594		
B / H	3	50.664	40.805	24.161		
B / H	6	52.638	41.865	25.733		
B / H	8	51.591	42.135	22.442	**Mean**	**24.175**
B / H	9	51.983	41.940	23.946	**STE**	**0.532**

Date collected: 03/09/03

Treatment*	Macroplot #	wet soil (g)	dry soil (g)	% Grav moisture		
C	2	17.640	14.741	19.670		
C	4	17.846	14.942	19.436		
C	5	16.271	13.025	24.921		
C	7	14.015	11.020	27.182	**Mean**	**22.882**
C	10	16.188	13.139	23.202	**STE**	**1.499**
H	2	17.786	14.969	18.819		
H	4	12.387	10.061	23.119		
H	5	17.210	13.819	24.539		
H	7	16.218	12.816	26.540	**Mean**	**23.145**
H	10	15.342	12.503	22.707	**STE**	**1.272**
B	1	15.593	12.834	21.496		
B	3	17.027	14.245	19.527		
B	6	16.510	12.853	28.451		
B	8	16.380	13.246	23.659	**Mean**	**22.064**
B	9	15.350	13.099	17.189	**STE**	**1.922**
B / H	1	15.636	12.770	22.444		
B / H	3	14.434	12.042	19.865		
B / H	6	14.414	11.441	25.989		
B / H	8	15.782	13.063	20.814	**Mean**	**22.753**
B / H	9	15.414	12.365	24.651	**STE**	**1.146**

* C = control , H = herbicide applied , B = burned , BH = burned and herbicided

Appendix C. % Gravimetric Soil Moisture by Treatment by Date. Continued.

Date collected: 04/01/03

Treatment*	Macroplot #	wet soil (g)	dry soil (g)	% Grav moisture		
C	2	18.621	15.223	22.321		
C	4	17.286	14.673	17.808		
C	5	16.568	13.524	22.508		
C	7	17.877	13.480	32.619	**Mean**	**23.903**
C	10	18.195	14.643	24.257	**STE**	**2.426**
H	2	18.850	15.478	21.786		
H	4	16.811	13.534	24.213		
H	5	17.890	14.156	26.378		
H	7	18.326	14.767	24.101	**Mean**	**24.082**
H	10	18.497	14.925	23.933	**STE**	**0.727**
B	1	18.814	15.508	21.318		
B	3	18.833	16.085	17.084		
B	6	16.772	13.739	22.076		
B	8	16.467	13.258	24.204	**Mean**	**20.788**
B	9	18.924	15.868	19.259	**STE**	**1.218**
B / H	1	19.620	16.124	21.682		
B / H	3	19.529	16.125	21.110		
B / H	6	16.144	14.257	13.236		
B / H	8	18.447	15.255	20.924	**Mean**	**19.248**
B / H	9	18.902	15.846	19.286	**STE**	**1.555**

Date collected: 05/03/03

Treatment*	Macroplot #	wet soil (g)	dry soil (g)	% Grav moisture		
C	2	18.856	15.894	18.636		
C	4	18.651	15.945	16.971		
C	5	16.810	13.719	22.531		
C	7	18.022	14.235	26.603	**Mean**	**21.242**
C	10	18.752	15.438	21.467	**STE**	**1.666**
H	2	18.794	15.572	20.691		
H	4	19.951	16.508	20.857		
H	5	18.930	15.401	22.914		
H	7	18.283	14.775	23.743	**Mean**	**23.431**
H	10	18.339	14.222	28.948	**STE**	**1.499**
B	1	16.679	13.688	21.851		
B	3	16.271	13.600	19.640		
B	6	18.371	14.567	26.114		
B	8	15.614	12.837	21.633	**Mean**	**21.062**
B	9	18.299	15.765	16.074	**STE**	**1.634**
B / H	1	18.014	14.957	20.439		
B / H	3	18.658	14.720	26.753		
B / H	6	17.747	14.420	23.072		
B / H	8	17.831	14.858	20.009	**Mean**	**21.776**
B / H	9	18.849	15.892	18.607	**STE**	**1.439**

* C = control , H = herbicide applied , B = burned , BH = burned and herbicided

Appendix C. % Gravimetric Soil Moisture by Treatment by Date. Continued.

Date collected: 06/12/03

Treatment*	Macroplot #	wet soil (g)	dry soil (g)	% Grav moisture		
C	2	13.307	12.757	4.311		
C	4	13.853	13.125	5.547		
C	5	14.428	13.163	9.610		
C	7	11.604	10.625	9.214	**Mean**	**6.886**
C	10	13.097	12.385	5.749	**STE**	**1.062**
H	2	17.775	15.190	17.018		
H	4	12.903	11.804	9.310		
H	5	14.878	12.404	19.945		
H	7	12.797	10.999	16.347	**Mean**	**15.538**
H	10	13.745	11.945	15.069	**STE**	**1.750**
B	1	12.787	11.652	9.741		
B	3	13.614	12.413	9.675		
B	6	12.435	11.298	10.064		
B	8	12.282	11.267	9.009	**Mean**	**10.061**
B	9	13.645	12.203	11.817	**STE**	**0.471**
B / H	1	15.276	13.745	11.139		
B / H	3	13.934	11.895	17.142		
B / H	6	15.249	12.978	17.499		
B / H	8	15.049	13.483	11.615	**Mean**	**14.704**
B / H	9	15.720	13.537	16.126	**STE**	**1.379**

Date collected: 07/18/03

Treatment*	Macroplot #	wet soil (g)	dry soil (g)	% Grav moisture		
C	2	41.972	37.523	11.857		
C	4	40.246	38.893	3.479		
C	5	38.471	35.791	7.488		
C	7	43.801	38.959	12.428	**Mean**	**8.860**
C	10	44.177	40.512	9.047	**STE**	**1.622**
H	2	38.696	32.637	18.565		
H	4	36.000	32.144	11.996		
H	5	16.915	14.706	15.021		
H	7	40.282	34.485	16.810	**Mean**	**14.863**
H	10	39.824	35.581	11.925	**STE**	**1.311**
B	1	46.477	43.098	7.840		
B	3	40.948	36.303	12.795		
B	6	29.433	26.556	10.834		
B	8	40.815	37.860	7.805	**Mean**	**8.464**
B	9	48.008	46.588	3.048	**STE**	**1.651**
B / H	1	15.034	13.760	9.259		
B / H	3	15.814	13.913	13.663		
B / H	6	15.562	13.901	11.949		
B / H	8	44.512	36.501	21.947	**Mean**	**13.714**
B / H	9	35.331	31.615	11.754	**STE**	**2.175**

* C = control , H = herbicide applied , B = burned , BH = burned and herbicided

Appendix C. % Gravimetric Soil Moisture by Treatment by Date. Continued.

Date collected: 12/07/03

Treatment*	Macroplot #	wet soil (g)	dry soil (g)	% Grav moisture		
C	2	19.408	16.726	16.035		
C	4	16.346	15.569	4.991		
C	5	14.723	13.536	8.769		
C	7	14.060	12.835	9.544	**Mean**	**10.803**
C	10	18.181	15.854	14.678	**STE**	**2.023**
H	2	12.774	11.868	7.634		
H	4	20.094	16.952	18.535		
H	5	13.032	11.787	10.562		
H	7	14.895	13.410	11.074	**Mean**	**11.476**
H	10	14.031	12.805	9.574	**STE**	**1.860**
B	1	15.551	14.305	8.710		
B	3	15.322	13.834	10.756		
B	6	16.445	14.549	13.032		
B	8	13.486	12.344	9.251	**Mean**	**12.074**
B	9	19.256	16.233	18.623	**STE**	**1.800**
B / H	1	15.979	14.602	9.430		
B / H	3	18.712	15.810	18.357		
B / H	6	16.634	15.100	10.159		
B / H	8	15.231	14.041	8.475	**Mean**	**12.749**
B / H	9	20.176	17.197	17.323	**STE**	**2.102**

* C = control , H = herbicide applied , B = burned , BH = burned and herbicided

Appendix D. Soil Analyses.

Soil Samples for CEC, pH, and OM (loss on ignition) Averaged *By Treatment*

Date Collected: 5/06/03

Treatment*	Sample #	Location	pH	OM (LOI)	CEC (meq/100g)
C	104	2NH	7.00	3.370	13.40
C	108	4NH	6.80	3.990	12.60
C	110	5NH	7.00	5.650	21.80
C	114	7NH	7.00	4.630	21.00
C	120	10NH	6.90	4.270	19.40
		Mean	**6.94**	**4.38**	**17.64**
		STE	**0.04**	**0.38**	**1.94**
H	103	2H	6.90	4.40	17.00
H	107	4H	7.00	3.86	15.10
H	109	5H	6.90	4.45	18.40
H	113	7H	6.90	5.46	21.60
H	119	10H	6.80	3.96	17.80
		Mean	**6.90**	**4.43**	**17.98**
		STE	**0.03**	**0.28**	**1.06**
B	102	1NH	6.90	4.04	17.10
B	106	3NH	6.90	4.01	15.10
B	112	6NH	6.90	4.81	18.00
B	116	8NH	6.90	4.26	18.80
B	118	9NH	6.80	4.09	16.00
		Mean	**6.88**	**4.24**	**17.00**
		STE	**0.02**	**0.15**	**0.67**
BH	101	1H	6.80	4.10	16.40
BH	105	3H	6.80	4.23	16.50
BH	111	6H	6.90	4.24	17.40
BH	115	8H	7.10	3.53	16.60
BH	117	9H	6.90	4.27	17.80
		Mean	**6.90**	**4.07**	**16.94**
		STE	**0.06**	**0.14**	**0.28**

* C = control , H = herbicide applied , B = burned , BH = burned and herbicided

Appendix D. Soil Analyses. Continued.

Soil Samples for CEC, pH, and OM (loss on ignition) Averaged *By Block*

Date Collected: 5/06/03

Block	Treatment*	Sample #	Location	pH	OM (LOI)	CEC (meq/100g)
1	B	102	1NH	6.90	4.04	17.10
1	BH	101	1H	6.80	4.10	16.40
1	C	104	2NH	7.00	3.37	13.40
1	H	103	2H	6.90	4.40	17.00
			Mean	**6.90**	**3.98**	**15.98**
			STE	**0.04**	**0.22**	**0.87**
2	B	106	3NH	6.90	4.01	15.10
2	BH	105	3H	6.80	4.23	16.50
2	C	108	4NH	6.80	3.99	12.60
2	H	107	4H	7.00	3.86	15.10
			Mean	**6.88**	**4.02**	**14.83**
			STE	**0.05**	**0.08**	**0.81**
3	B	112	6NH	6.90	4.81	18.00
3	BH	111	6H	6.90	4.24	17.40
3	C	110	5NH	7.00	5.65	21.80
3	H	109	5H	6.90	4.45	18.40
			Mean	**6.93**	**4.79**	**18.90**
			STE	**0.03**	**0.31**	**0.99**
4	B	116	8NH	6.90	4.26	18.80
4	BH	115	8H	7.10	3.53	16.60
4	C	114	7NH	7.00	4.63	21.00
4	H	113	7H	6.90	5.46	21.60
			Mean	**6.98**	**4.47**	**19.50**
			STE	**0.05**	**0.40**	**1.14**
5	B	118	9NH	6.80	4.09	16.00
5	BH	117	9H	6.90	4.27	17.80
5	C	120	10NH	6.90	4.27	19.40
5	H	119	10H	6.80	3.96	17.80
			Mean	**6.85**	**4.15**	**17.75**
			STE	**0.03**	**0.08**	**0.69**

* C = control , H = herbicide applied , B = burned , BH = burned and herbicided

Appendix E. Density Reductions for *B. tectorum*. ANOVAs and Contrasts.

Bromus tectorum L.

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	7.17	0.0554
herbicide (H)	1	8	4.31	0.0715
burn*herbicide	1	8	2.46	0.1556
weeded (W)	1	16	64.38	< 0.001
herbicide*weeded	1	16	0.07	0.8017
burn*weeded	1	16	1.63	0.2198
burn*weeded*herbicide	1	16	4.37	0.0529

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
weeded			N	2.9330	0.2030	16	14.45	<.0001	0.05	2.503	3.363
weeded			Y	0.8910	0.2030	16	4.39	0.0005	0.05	0.461	1.321
B*H*W	N	N	N	3.3660	0.4060	16	8.29	<.0001	0.05	2.505	4.227
B*H*W	N	N	Y	1.4660	0.4060	16	3.61	0.0023	0.05	0.605	2.327
B*H*W	N	Y	N	3.4120	0.4060	16	8.40	<.0001	0.05	2.551	4.273
B*H*W	N	Y	Y	1.0980	0.4060	16	2.70	0.0156	0.05	0.237	1.959
B*H*W	Y	N	N	3.4820	0.4060	16	8.58	<.0001	0.05	2.621	4.343
B*H*W	Y	N	Y	0.6480	0.4060	16	1.60	0.1301	0.05	-0.213	1.509
B*H*W	Y	Y	N	1.4720	0.4060	16	3.63	0.0023	0.05	0.611	2.333
B*H*W	Y	Y	Y	0.3520	0.4060	16	0.87	0.3988	0.05	-0.509	1.213

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	-0.0460	0.5742	16	-0.08	0.9371	0.05	-1.056	0.964
C	VS	B	-0.1160	0.5742	16	-0.20	0.8425	0.05	-1.126	0.894
C	VS	BH	1.8940	0.5742	16	3.30	0.0045	0.05	0.884	2.904
H	VS	B	-0.0700	0.5742	16	-0.12	0.9045	0.05	-1.080	0.940
H	VS	BH	1.9400	0.5742	16	3.38	0.0038	0.05	0.930	2.950
B	VS	BH	2.0100	0.5742	16	3.50	0.0030	0.05	1.000	3.020
W	VS	H	-1.9460	0.5742	16	-3.39	0.0037	0.05	-2.956	-0.936
BW	VS	BH	-0.8240	0.5742	16	-1.43	0.1706	0.05	-1.834	0.186

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix F. Seed Set Reductions for *B. tectorum*. ANOVAs and Contrasts.

Bromus tectorum L. **(square root transformed)**

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	1.68	0.2651
herbicide (H)	1	8	278.59	<0.001
burn*herbicide	1	8	5.44	0.0480
weeded (W)	1	16	0.07	0.7941
herbicide*weeded	1	16	0.00	0.9618
burn*weeded	1	16	0.56	0.4643
burn*weeded*herbicide	1	16	0.03	0.8548

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
herbicide		N		2.2741	0.0851	8	26.74	<.0001	0.05	2.078	2.470
herbicide		Y		0.5036	0.0851	8	5.92	0.0004	0.05	0.308	0.700
B*H	N	N		2.0643	0.1203	8	17.16	<.0001	0.05	1.787	2.342
B*H	N	Y		0.5412	0.1203	8	4.50	0.0020	0.05	0.264	0.819
B*H	Y	N		2.4838	0.1203	8	20.65	<.0001	0.05	2.206	2.761
B*H	Y	Y		0.4660	0.1203	8	3.87	0.0047	0.05	0.189	0.743

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	1.4959	0.1648	16	9.08	<.0001	0.05	1.186	1.806
C	VS	B	-0.4128	0.1833	16	-2.25	0.0387	0.05	-0.723	-0.121
C	VS	BH	1.5598	0.1833	16	8.51	<.0001	0.05	1.250	1.870
H	VS	B	-1.9088	0.1833	16	-10.4	<.0001	0.05	-2.219	-1.599
H	VS	BH	0.0638	0.1833	16	0.35	0.732	0.05	-0.246	0.374
B	VS	BH	1.9726	0.1648	16	11.97	<.0001	0.05	1.663	2.283
W	VS	H	1.5383	0.1648	16	9.33	<.0001	0.05	1.228	1.848
BW	VS	BH	2.0282	0.1648	16	12.31	<.0001	0.05	1.718	2.338

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix G. Density Reductions for *T. caput-medusae*. ANOVAs and Contrasts.

Taeniatherum caput-medusae (L.) Nevski **(natural log transformed)**

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	10.28	0.0327
herbicide (H)	1	8	122.37	< 0.001
burn*herbicide	1	8	0.06	0.8110
weeded (W)	1	16	51.43	< 0.001
herbicide*weeded	1	16	0.00	0.9512
burn*weeded	1	16	0.29	0.5952
burn*weeded*herbicide	1	16	1.53	0.2338

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			1.3003	0.2813	4	4.62	0.0099	0.05	0.519	2.081
burn	Y			0.5141	0.2813	4	1.83	0.1416	0.05	-0.267	1.295
herbicide		N		2.2633	0.2813	8	8.05	<.0001	0.05	1.615	2.912
herbicide		Y		-0.4489	0.2813	8	-1.60	0.1492	0.05	-1.097	0.200
weeded			N	1.7864	0.2813	16	6.35	<.0001	0.05	1.190	2.383
weeded			Y	0.0280	0.2813	16	0.10	0.9219	0.05	-0.568	0.624

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	2.2152	0.4904	16	4.52	0.0004	0.05	1.173	3.257
C	VS	B	0.4375	0.4904	16	0.89	0.3855	0.05	-0.605	1.480
C	VS	BH	3.3807	0.4904	16	6.89	<.0001	0.05	2.339	4.423
H	VS	B	-1.7778	0.4904	16	-3.63	0.002	0.05	-2.820	-0.736
H	VS	BH	1.1654	0.4904	16	2.38	0.0303	0.05	0.123	2.207
B	VS	BH	2.9432	0.4904	16	6.00	<.0001	0.05	1.901	3.985
W	VS	H	0.8779	0.4904	16	1.79	0.0923	0.05	-0.164	1.920
BW	VS	BH	1.0296	0.4904	16	2.10	0.0520	0.05	-0.012	2.072

* where
C = control
W = weeded
H = herbicide applied
B = burned
BW = burned & weeded
BH = burned & herbicided

Appendix H. Seed Set Reductions for *T. caput-medusae*. ANOVAs and Contrasts.

Taeniatherum caput-medusae (L.) Nevski **(natural log transformed)**

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	30.83	0.0051
herbicide (H)	1	8	47.31	<0.001
burn*herbicide	1	8	5.06	0.0545
weeded (W)	1	16	0.02	0.8888
herbicide*weeded	1	16	0.00	0.9574
burn*weeded	1	16	0.10	0.7594
burn*weeded*herbicide	1	16	0.00	0.9782

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			0.2489	0.1362	4	1.83	0.1416	0.05	-0.129	0.627
burn	Y			1.3181	0.1362	4	9.68	0.0006	0.05	0.940	1.696
herbicide		N		1.3732	0.1289	8	10.65	<.0001	0.05	1.076	1.671
herbicide		Y		0.1937	0.1289	8	1.50	0.1714	0.05	-0.104	0.491
B*H	N	N		1.0316	0.1823	8	5.66	0.0005	0.05	0.611	1.452
B*H	N	Y		-0.5338	0.1823	8	-2.93	0.0191	0.05	-0.954	-0.113
B*H	Y	N		1.7149	0.1823	8	9.41	<.0001	0.05	1.294	2.135
B*H	Y	Y		0.9213	0.1823	8	5.05	0.0010	0.05	0.501	1.342

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	1.5284	0.2875	16	5.32	<.0001	0.05	0.941	2.115
C	VS	B	-0.6922	0.3005	16	-2.30	0.0350	0.05	-1.279	-0.105
C	VS	BH	0.0704	0.3005	16	0.23	0.8178	0.05	-0.517	0.657
H	VS	B	-2.2206	0.3005	16	-7.39	<.0001	0.05	-2.808	-1.634
H	VS	BH	-1.4580	0.3005	16	-4.85	0.0002	0.05	-2.045	-0.871
B	VS	BH	0.7626	0.2875	16	2.65	0.0174	0.05	0.176	1.350
W	VS	H	1.5559	0.2875	16	5.41	<.0001	0.05	0.969	2.143
BW	VS	BH	0.7721	0.2875	16	2.69	0.0162	0.05	0.185	1.359

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix I. Average Proportional Emergence. ANOVAs and Contrasts.

Elymus multisetus M.E. Jones

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	3.45	0.1367
herbicide (H) (burn)	2	8	4.20	0.0567
weeded (W)	1	16	9.28	0.0077
burn*weeded	1	16	0.38	0.5454
herbicide*weeded (burn)	2	16	11.78	0.0007

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
weeded			N	0.1892	0.0119	16	15.90	<.0001	0.05	0.164	0.214
weeded			Y	0.1671	0.0119	16	14.04	<.0001	0.05	0.142	0.192
H*W(B)	N	N	N	0.1537	0.0204	16	7.55	<.0001	0.05	0.111	0.197
H*W(B)	N	N	Y	0.1858	0.0204	16	9.12	<.0001	0.05	0.143	0.229
H*W(B)	N	Y	N	0.2623	0.0204	16	12.88	<.0001	0.05	0.219	0.306
H*W(B)	N	Y	Y	0.1951	0.0204	16	9.58	<.0001	0.05	0.152	0.238
H*W(B)	Y	N	N	0.1753	0.0204	16	8.61	<.0001	0.05	0.132	0.219
H*W(B)	Y	N	Y	0.1469	0.0204	16	7.21	<.0001	0.05	0.104	0.190
H*W(B)	Y	Y	N	0.1654	0.0204	16	8.12	<.0001	0.05	0.122	0.209
H*W(B)	Y	Y	Y	0.1407	0.0204	16	6.91	<.0001	0.05	0.098	0.184

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	-0.1086	0.0230	16	-4.7	2E-04	0.05	-0.157	-0.060
C	VS	B	-0.0216	0.0288	16	-0.8	0.464	0.05	-0.083	0.039
C	VS	BH	-0.0117	0.0288	16	-0.4	0.689	0.05	-0.073	0.049
H	VS	B	0.0870	0.0288	16	3.02	0.008	0.05	0.026	0.148
H	VS	BH	0.0969	0.0288	16	3.36	0.004	0.05	0.036	0.158
B	VS	BH	0.0099	0.0230	16	0.43	0.673	0.05	-0.039	0.059
W	VS	H	-0.0765	0.0230	16	-3.3	0.004	0.05	-0.125	-0.028
BW	VS	BH	-0.0185	0.0230	16	-0.8	0.432	0.05	-0.067	0.030

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix I. Average Proportional Emergence. ANOVAs/Contrasts. Continued.

Elymus wawawaiensis J. Carlson & Barkworth

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	2.67	0.1773
herbicide (H) (burn)	2	8	5.08	0.0377
weeded (W)	1	16	0.00	0.9676
burn*weeded	1	16	0.44	0.5180
herbicide*weeded (burn)	2	16	1.22	0.3220

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
H (B)	N	N		0.1867	0.0321	8	5.82	0.0004	0.05	0.113	0.261
H (B)	N	Y		0.2870	0.0321	8	8.95	<.0001	0.05	0.213	0.361
H (B)	Y	N		0.2846	0.0321	8	8.87	<.0001	0.05	0.211	0.359
H (B)	Y	Y		0.2960	0.0321	8	9.22	<.0001	0.05	0.222	0.370

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	-0.0605	0.0448	16	-1.35	0.1958	0.05	-0.156	0.035
C	VS	B	-0.1074	0.0507	16	-2.12	0.0502	0.05	-0.215	0.000
C	VS	BH	-0.0895	0.0507	16	-1.76	0.0967	0.05	-0.197	0.018
H	VS	B	-0.0469	0.0507	16	-0.92	0.3687	0.05	-0.154	0.061
H	VS	BH	-0.0290	0.0507	16	-0.57	0.5753	0.05	-0.137	0.079
B	VS	BH	0.0179	0.0448	16	0.40	0.6948	0.05	-0.077	0.113
W	VS	H	-0.0846	0.0448	16	-1.89	0.0774	0.05	-0.180	0.010
BW	VS	BH	-0.0253	0.0448	16	-0.56	0.5801	0.05	-0.120	0.070

* where C = control, W = weeded, H = herbicide applied, B = burned, BW = burned & weeded, BH = burned & herbicided

Appendix I. Average Proportional Emergence. ANOVAs/Contrasts. Continued.

Artemisia tridentata Nutt. ssp. ***wyomingensis*** (Beetle and Young)

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	11.04	0.0293
herbicide (H) (burn)	2	8	0.63	0.5584
weeded (W)	1	16	2.15	0.1624
burn*weeded	1	16	5.06	0.0389
herbicide*weeded (burn)	2	16	0.06	0.9380

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			0.6083	0.0638	4	9.53	0.0007	0.05	0.431	0.786
burn	Y			0.3791	0.0638	4	5.94	0.0040	0.05	0.202	0.556
B*W	N		N	0.6846	0.0701	16	9.77	<.0001	0.05	0.536	0.833
B*W	N		Y	0.5321	0.0701	16	7.59	<.0001	0.05	0.384	0.681
B*W	Y		N	0.3630	0.0701	16	5.18	<.0001	0.05	0.214	0.512
B*W	Y		Y	0.3952	0.0701	16	5.64	<.0001	0.05	0.247	0.544

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	0.1000	0.1135	16	0.88	0.3915	0.05	-0.141	0.341
C	VS	B	0.3611	0.1135	16	3.18	0.0058	0.05	0.120	0.602
C	VS	BH	0.3821	0.1135	16	3.37	0.0039	0.05	0.141	0.623
H	VS	B	0.2611	0.1135	16	2.30	0.0353	0.05	0.020	0.502
H	VS	BH	0.2821	0.1135	16	2.48	0.0244	0.05	0.041	0.523
B	VS	BH	0.0210	0.1135	16	0.18	0.8557	0.05	-0.220	0.262
W	VS	H	-0.0432	0.1135	16	-0.38	0.7085	0.05	-0.284	0.198
BW	VS	BH	0.0346	0.1135	16	0.30	0.7647	0.05	-0.206	0.275

* where

C	= control	B	= burned
W	= weeded	BW	= burned & weeded
H	= herbicide applied	BH	= burned & herbicided

Appendix I. Average Proportional Emergence. ANOVAs/Contrasts. Continued.

Achillea millefolium L. var. *occidentalis* D.C. **(natural log transformed)**

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	16.24	0.0157
herbicide (H) (burn)	2	8	1.80	0.2264
weeded (W)	1	16	0.58	0.4588
burn*weeded	1	16	1.03	0.3249
herbicide*weeded (burn)	2	16	1.26	0.3094

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			-0.9740	0.1675	4	-5.81	0.0044	0.05	-1.439	-0.509
burn	Y			-1.5124	0.1675	4	-9.03	0.0008	0.05	-1.978	-1.047

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	-0.0282	0.2449	16	-0.11	0.9099	0.05	-0.547	0.491
C	VS	B	0.3908	0.2449	16	1.60	0.1301	0.05	-0.128	0.910
C	VS	BH	0.8817	0.2449	16	3.60	0.0024	0.05	0.363	1.401
H	VS	B	0.4190	0.2449	16	1.71	0.1065	0.05	-0.100	0.938
H	VS	BH	0.9098	0.2449	16	3.71	0.0019	0.05	0.391	1.429
B	VS	BH	0.4909	0.2449	16	2.00	0.0623	0.05	-0.028	1.010
W	VS	H	-0.0412	0.2449	16	-0.17	0.8687	0.05	-0.560	0.478
BW	VS	BH	0.3517	0.2449	16	1.44	0.1702	0.05	-0.168	0.871

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix I. Average Proportional Emergence. ANOVAs/Contrasts. Continued.

Poa secunda J. Presl

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	0.13	0.7374
herbicide (H) (burn)	2	8	1.59	0.2625
weeded (W)	1	16	0.90	0.3556
burn*weeded	1	16	1.79	0.1999
herbicide*weeded (burn)	2	16	1.09	0.3599

Appendix J. Average Overall Seedling Density. ANOVAs and Contrasts.

Poa secunda J. Presl **(natural log transformed)**

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	1.03	0.3673
herbicide (H) (burn)	2	8	1.03	0.3987
weeded (W)	1	16	10.52	0.0051
burn*weeded	1	16	8.25	0.0111
herbicide*weeded (burn)	2	16	5.57	0.0146

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	LOWER	UPPER
weeded			N	1.5304	0.3370	16	4.54	0.0003	0.05	0.816	2.245
weeded			Y	2.3210	0.3370	16	6.89	<.0001	0.05	1.607	3.035
B*W	N		N	1.4024	0.4198	16	3.34	0.0042	0.05	0.512	2.292
B*W	N		Y	2.8933	0.4198	16	6.89	<.0001	0.05	2.003	3.783
B*W	Y		N	1.6583	0.4198	16	3.95	0.0011	0.05	0.768	2.548
B*W	Y		Y	1.7487	0.4198	16	4.17	0.0007	0.05	0.859	2.639
H*W(B)	N	N	N	1.9998	0.4855	16	4.12	0.0008	0.05	0.971	3.029
H*W(B)	N	N	Y	2.5413	0.4855	16	5.23	<.0001	0.05	1.512	3.571
H*W(B)	N	Y	N	0.8051	0.4855	16	1.66	0.1167	0.05	-0.224	1.834
H*W(B)	N	Y	Y	3.2453	0.4855	16	6.68	<.0001	0.05	2.216	4.274
H*W(B)	Y	N	N	1.5485	0.4855	16	3.19	0.0057	0.05	0.519	2.578
H*W(B)	Y	N	Y	2.2893	0.4855	16	4.72	0.0002	0.05	1.260	3.318
H*W(B)	Y	Y	N	1.7682	0.4855	16	3.64	0.0022	0.05	0.739	2.797
H*W(B)	Y	Y	Y	1.2081	0.4855	16	2.49	0.0242	0.05	0.179	2.237

CONTRASTS*			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	1.1947	0.4876	16	2.45	0.0262	0.05	0.161	2.228
C	VS	B	0.4513	0.6081	16	0.74	0.4688	0.05	-0.838	1.740
C	VS	BH	0.2316	0.6081	16	0.38	0.7084	0.05	-1.058	1.521
H	VS	B	-0.7434	0.6081	16	-1.22	0.2392	0.05	-2.033	0.546
H	VS	BH	-0.9631	0.6081	16	-1.58	0.1328	0.05	-2.252	0.326
B	VS	BH	-0.2197	0.4876	16	-0.45	0.6583	0.05	-1.253	0.814
W	VS	H	1.7362	0.4876	16	3.56	0.0026	0.05	0.703	2.770
BW	VS	BH	0.5211	0.4876	16	1.07	0.3011	0.05	-0.513	1.555

* where C = control, W = weeded, H = herbicide applied, B = burned, BW = burned & weeded, BH = burned & herbicided

Appendix K. Average Log Emergence Times. ANOVAs and Contrasts.

Elymus multisetus M.E. Jones

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	28.17	0.0061
herbicide (H) (burn)	2	8	2.49	0.1446
weeded (W)	1	16	4.91	0.0416
burn*weeded	1	16	3.26	0.0897
herbicide*weeded (burn)	2	16	2.24	0.1392

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			6.5525	0.0855	4	76.68	<.0001	0.05	6.315	6.790
burn	Y			7.1650	0.0855	4	83.84	<.0001	0.05	6.928	7.402
weeded			N	6.7598	0.0773	16	87.50	<.0001	0.05	6.596	6.924
weeded			Y	6.9577	0.0773	16	90.07	<.0001	0.05	6.794	7.122

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	0.5313	0.2064	16	2.57	0.02	0.05	0.094	0.969
C	VS	B	-0.0165	0.2064	16	-0.08	0.937	0.05	-0.454	0.421
C	VS	BH	-0.3544	0.2064	16	-1.72	0.105	0.05	-0.792	0.083
H	VS	B	-0.5478	0.2064	16	-2.65	0.017	0.05	-0.985	-0.110
H	VS	BH	-0.8857	0.2064	16	-4.29	6E-04	0.05	-1.323	-0.448
B	VS	BH	-0.3379	0.2064	16	-1.64	0.121	0.05	-0.775	0.100
W	VS	H	0.3320	0.2064	16	1.61	0.127	0.05	-0.106	0.769
BW	VS	BH	0.1467	0.2064	16	0.71	0.488	0.05	-0.291	0.584

* where
C = control
W = weeded
H = herbicide applied
B = burned
BW = burned & weeded
BH = burned & herbicided

Appendix K. Average Log Emergence Times. ANOVAs/Contrasts. Continued.

Elymus wawawaiensis J. Carlson & Barkworth

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	0.03	0.8762
herbicide (H) (burn)	2	8	2.81	0.1192
weeded (W)	1	16	0.05	0.8199
burn*weeded	1	16	0.31	0.5881
herbicide*weeded (burn)	2	16	0.33	0.7235

Appendix K. Average Log Emergence Times. ANOVAs/Contrasts. Continued.

Artemisia tridentata Nutt. ssp. *wyomingensis* (Beetle and Young)

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	14.21	0.0196
herbicide (H) (burn)	2	8	0.51	0.6173
weeded (W)	1	16	0.54	0.4749
burn*weeded	1	16	1.50	0.2388
herbicide*weeded (burn)	2	16	0.10	0.9091

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			5.0077	0.2605	4	19.22	<.0001	0.05	4.285	5.731
burn	Y			6.1776	0.2605	4	23.72	<.0001	0.05	5.454	6.901

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	-0.3842	0.5212	16	-0.74	0.472	0.05	-1.489	0.721
C	VS	B	-1.6481	0.5212	16	-3.16	0.0060	0.05	-2.753	-0.543
C	VS	BH	-1.5625	0.5212	16	-3.00	0.009	0.05	-2.667	-0.458
H	VS	B	-1.2639	0.5212	16	-2.42	0.028	0.05	-2.369	-0.159
H	VS	BH	-1.1782	0.5212	16	-2.26	0.038	0.05	-2.283	-0.073
B	VS	BH	0.0857	0.5212	16	0.16	0.872	0.05	-1.019	1.191
W	VS	H	-0.0553	0.5212	16	-0.11	0.917	0.05	-1.160	1.050
BW	VS	BH	-0.1198	0.5212	16	-0.23	0.821	0.05	-1.225	0.985

* where

C = control
W = weeded
H = herbicide applied
B = burned
BW = burned & weeded
BH = burned & herbicided

Appendix K. Average Log Emergence Times. ANOVAs/Contrasts. Continued.

Achillea millefolium L. var. *occidentalis* D.C.

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	16.44	0.0154
herbicide (H) (burn)	2	8	3.73	0.0717
weeded (W)	1	16	1.65	0.2172
burn*weeded	1	16	1.57	0.2280
herbicide*weeded (burn)	2	16	1.07	0.3672

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			5.1216	0.1725	4	29.69	<.0001	0.05	4.643	5.601
burn	Y			5.8995	0.1725	4	34.20	<.0001	0.05	5.421	6.379

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	-0.1436	0.3349	16	-0.43	0.674	0.05	-0.854	0.566
C	VS	B	-0.6442	0.3349	16	-1.92	0.072	0.05	-1.354	0.066
C	VS	BH	-1.4032	0.3349	16	-4.19	7E-04	0.05	-2.113	-0.693
H	VS	B	-0.5005	0.3349	16	-1.49	0.154	0.05	-1.210	0.209
H	VS	BH	-1.2595	0.3349	16	-3.76	0.002	0.05	-1.969	-0.550
B	VS	BH	-0.7590	0.3349	16	-2.27	0.038	0.05	-1.469	-0.049
W	VS	H	-0.0453	0.3349	16	-0.14	0.894	0.05	-0.755	0.665
BW	VS	BH	-0.6214	0.3349	16	-1.86	0.0820	0.05	-1.331	0.089

* where

C	= control	B	= burned
W	= weeded	BW	= burned & weeded
H	= herbicide applied	BH	= burned & herbicided

Appendix K. Average Log Emergence Times. ANOVAs/Contrasts. Continued.

Poa secunda J. Presl

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	7.12	0.0559
herbicide (H) (burn)	2	8	1.34	0.3160
weeded (W)	1	16	3.77	0.0701
burn*weeded	1	16	2.88	0.1089
herbicide*weeded (burn)	2	16	0.63	0.5474

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			4.9212	0.1895	4	25.97	<.0001	0.05	4.395	5.447
burn	Y			5.2240	0.1895	4	27.56	<.0001	0.05	4.698	5.750

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	-0.3822	0.2059	16	-1.86	0.082	0.05	-0.819	0.054
C	VS	B	-0.3543	0.2059	16	-1.72	0.105	0.05	-0.791	0.082
C	VS	BH	-0.3242	0.2059	16	-1.57	0.135	0.05	-0.761	0.112
H	VS	B	0.0279	0.2059	16	0.14	0.894	0.05	-0.409	0.464
H	VS	BH	0.0580	0.2059	16	0.28	0.782	0.05	-0.379	0.494
B	VS	BH	0.0301	0.2059	16	0.15	0.886	0.05	-0.406	0.467
W	VS	H	-0.2365	0.2059	16	-1.15	0.268	0.05	-0.673	0.200
BW	VS	BH	0.2874	0.2059	16	1.40	0.1818	0.05	-0.149	0.724

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix L. Average Log Mortality Times. ANOVAs and Contrasts.

Elymus multisetus M.E. Jones

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	0.39	0.5677
herbicide (H) (burn)	2	8	4.19	0.0570
weeded (W)	1	16	5.69	0.0297
burn*weeded	1	16	0.07	0.7991
herbicide*weeded (burn)	2	16	1.72	0.2106

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
weeded			N	5.0954	0.0153	16	87.50	<.0001	0.05	5.063	5.128
weeded			Y	5.1364	0.0153	16	90.07	<.0001	0.05	5.104	5.169

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	0.0128	0.0344	16	0.37	0.714	0.05	-0.060	0.086
C	VS	B	0.0068	0.0391	16	0.18	0.863	0.05	-0.076	0.090
C	VS	BH	0.0286	0.0391	16	0.73	0.475	0.05	-0.054	0.112
H	VS	B	-0.0060	0.0391	16	-0.15	0.88	0.05	-0.089	0.077
H	VS	BH	0.0158	0.0391	16	0.40	0.691	0.05	-0.067	0.099
B	VS	BH	0.0218	0.0344	16	0.63	0.5350	0.05	-0.051	0.095
W	VS	H	0.0785	0.0344	16	2.28	0.036	0.05	0.006	0.151
BW	VS	BH	0.0986	0.0344	16	2.87	0.011	0.05	0.026	0.171

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix L. Average Log Mortality Times. ANOVAs and Contrasts. Continued.

Elymus wawawaiensis J. Carlson & Barkworth

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	0.18	0.6899
herbicide (H) (burn)	2	8	0.18	0.8366
weeded (W)	1	16	3.71	0.0719
burn*weeded	1	16	0.22	0.6419
herbicide*weeded (burn)	2	16	0.55	0.5876

Appendix L. Average Log Mortality Times. ANOVAs and Contrasts. Continued.

Artemisia tridentata Nutt. ssp. *wyomingensis* (Beetle and Young)

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	10.19	0.0331
herbicide (H) (burn)	2	8	0.83	0.4700
weeded (W)	1	16	1.19	0.2913
burn*weeded	1	16	0.85	0.3714
herbicide*weeded (burn)	2	16	1.50	0.2525

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			5.0103	0.0275	4	182	<.0001	0.05	4.934	5.087
burn	Y			4.8860	0.0275	4	177.50	<.0001	0.05	4.810	4.962

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	0.0145	0.0617	16	0.24	0.817	0.05	-0.116	0.145
C	VS	B	0.1239	0.0617	16	2.01	0.062	0.05	-0.007	0.255
C	VS	BH	0.1755	0.0617	16	2.84	0.012	0.05	0.045	0.306
H	VS	B	0.1094	0.0617	16	1.77	0.096	0.05	-0.021	0.240
H	VS	BH	0.1609	0.0617	16	2.61	0.019	0.05	0.030	0.292
B	VS	BH	0.0516	0.0617	16	0.84	0.416	0.05	-0.079	0.182
W	VS	H	0.0209	0.0617	16	0.34	0.739	0.05	-0.110	0.152
BW	VS	BH	0.0335	0.0617	16	0.54	0.595	0.05	-0.097	0.164

* where
C = control
W = weeded
H = herbicide applied
B = burned
BW = burned & weeded
BH = burned & herbicided

Appendix L. Average Log Mortality Times. ANOVAs and Contrasts. Continued.

Achillea millefolium L. var. *occidentalis* D.C.

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	7.68	0.0502
herbicide (H) (burn)	2	8	8.59	0.0102
weeded (W)	1	16	0.20	0.6584
burn*weeded	1	16	1.73	0.2064
herbicide*weeded (burn)	2	16	1.66	0.2212

Least Squares Means of Significant Effects

Effect	burn	herb	weed	LS MEAN	STE	DF	t	Pr > |t|	α	Lower	Upper
burn	N			5.0199	0.0150	4	333.4	<.0001	0.05	4.978	5.062
burn	Y			4.9651	0.0150	4	330.2	<.0001	0.05	4.923	5.007
H (B)	N	N		5.0444	0.0205	8	245.60	<.0001	0.05	4.997	5.092
H (B)	N	Y		4.9955	0.0205	8	243.22	<.0001	0.05	4.948	5.043
H (B)	Y	N		5.0177	0.0205	8	244.30	<.0001	0.05	4.970	5.065
H (B)	Y	Y		4.9125	0.0205	8	239.17	<.0001	0.05	4.865	4.959

Contrasts of Interest *

CONTRAST			Estimate	STE	DF	t	Pr > |t|	α	Lower	Upper
C	VS	H	0.0064	0.0396	16	0.16	0.873	0.05	-0.077	0.090
C	VS	B	0.0174	0.0396	16	0.44	0.666	0.05	-0.067	0.101
C	VS	BH	0.1509	0.0396	16	3.81	0.002	0.05	0.067	0.235
H	VS	B	0.0110	0.0396	16	0.28	0.785	0.05	-0.073	0.095
H	VS	BH	0.1444	0.0396	16	3.65	0.002	0.05	0.061	0.228
B	VS	BH	0.1335	0.0396	16	3.37	0.004	0.05	0.050	0.217
W	VS	H	0.0139	0.0396	16	0.35	0.73	0.05	-0.070	0.098
BW	VS	BH	0.1224	0.0396	16	3.09	0.007	0.05	0.038	0.206

* where C = control; W = weeded; H = herbicide applied; B = burned; BW = burned & weeded; BH = burned & herbicided

Appendix L. Average Log Mortality Times. ANOVAs and Contrasts. Continued.

Poa secunda J. Presl

The Mixed Procedure

Class Level Information

Class	Levels	Values
block	5	1 2 3 4 5
burn	2	N Y
herbicide	2	N Y
weeded	2	N Y

Tests of Fixed Effects

Source	NDF	DDF	F Value	Pr > F
burn (B)	1	4	1.18	0.3376
herbicide (H) (burn)	2	8	1.62	0.2570
weeded (W)	1	16	0.75	0.3986
burn*weeded	1	16	2.33	0.1461
herbicide*weeded (burn)	2	16	3.08	0.0739